Canada

Energy, Mines and
Resources Canada

Énergie, Mines et
Ressources Canada

TALL OIL AS FUEL
FOR MOBILE EQUIPMENT
IN THE KRAFT PULP INDUSTRY
PHASE II - PART II

PREPARED FOR:

RENEWABLE ENERGY BRANCH
ENERGY, MINES AND RESOURCES
OTTAWA, CANADA

DSS CONTRACT NO: 62SS.23216-4-6311

NOVEMBER 19, 1986

PREPARED BY:

L. A. LEWKO, Weyerhaeuser Canada Ltd.
(formerly Prince Albert Pulp Company Ltd.)
Box 3001
Prince Albert, Sask
S6V 5T5
Telephone: (306) 764-1521

W. B. REED, University of Saskatchewan

R. J. SECOR, Arbokem Inc.

SCIENTIFIC AUTHORITY:
Dr. A.J. Dolenko,
Director, Bioenergy Division

DISCLAIMER

This report is distributed for informational purposes only and does not necessarily reflect the views of the Government of Canada nor constitute an endorsement of any commercial product or person. Neither Canada nor its ministers, officers, employees or agents makes any warranty in respect of this report or assumes any liability arising out of this report.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Bioenergy Development Program of Energy, Mines and Resources Canada, and was obtained as an unsolicited proposal through the Department of Supply and Services of the Government of Canada.

The authors would like to acknowledge the support provided by the scientific authority for this project, Dr. A. J. Dolenko; and the technical liaison officer, Dr. J. F. G. MacKay.

This project would not have been possible without the initiative and preliminary work of Mr. P. Latos of Proctor and Gamble Inc. (Grande Prairie, Alta.), and Mr. O.K. Aschim of Prince Albert Pulp Company Ltd..

The authors would also like to thank the following people for their co-operation and assistance during this project.

Mr. A. Twa, Prince Albert Pulp Company Ltd.
Mr. A. Wong, Arbokem Inc., Beaconsfield, Quebec
Mr. L. McDiarmid, Prince Albert Pulp Company Ltd.
Mr. D. Farrer, University of Saskatchewan, Saskatoon, Sask.
Mr. P. Schmidt, University of Saskatchewan, Saskatoon, Sask.
Mr. D. Trumpy, POS Pilot Plant Corp., Saskatoon, Sask.
Mr. B. Zuk, Saskatchewan Research Council, Saskatoon, Sask.
Dr. I. Peggs, Hanson Materials Engineering (Western) Ltd., Edmonton, Alberta
Mr. M. Hagen, Federated Co-operative Refineries Ltd., Regina, Sask.

EXECUTIVE SUMMARY

"Tall Oil as Fuel for Mobile Equipment in the Kraft Pulp Industry - Phase II - Part II" outlines the developments of the work performed by the Prince Albert Pulp Company and the University of Saskatchewan (from February 1, 1985 to February 28, 1986) in the course of assessing the technical feasibility of using upgraded tall oil as a diesel alternative. Emphasis was placed on evaluating engine endurance over the longer term.

The results of this study indicate that fuel blends containing tall oil contribute to short fuel injector life. The fuel injectors repeatedly fail after 300-400 hours of operation on tall oil fuels. This failure is a combination of fouling of the injector tip with carbon deposits and of corrosion around the injector fuel port holes. This fuel injector problem seems to lead to higher than normal engine wear/corrosion and to increased combustion chamber deposits. It is felt that the major cause of the bearing wear/corrosion is lubrication oil breakdown, caused by fuel related contamination of the lubricating oil. The combustion chamber deposits were also found to be mostly fuel related. While these deposits did not directly affect engine performance over the length of the tests (up to 1570 hours), a continued buildup would result in excessive piston, ring and cylinder wear. Both of these problems are felt to be the result of fuel injector build up/failure.

Under the current price structure, the tall oil fuels are not economically viable. While the cost of crude tall oil is roughly 1/3 to 1/2 that of diesel, the inherent costs of processing, distribution, and increased engine maintenance negate this price differential. However, if the production of dewatered tall oil for fuel was integrated with tall oil fractionation for conventional markets, an economic advantage may exist. Moreover, the sale of tall oil fatty acids is often the limiting factor to the production output of tall oil fractionators. As a result, an alternate outlet for this material may prove to be very valuable.

In an effort to meet these future needs, further study on the technical feasibility of using tall oil fatty acids in the fuel blends should be undertaken. This study should initially concentrate on the reduction of fuel injector corrosion and deposit formation. This may be done by trying fuel additives or by reducing the concentration of the tall oil fatty acids in the fuel blend. Other alternatives may be discovered as the study proceeds. It is felt that the fuel injector problems are the major cause of the lubrication oil breakdown and the deposit formation in the combustion chamber, and that if the injector problems are solved, the other problems will be solved as well.

RÉSUMÉ POUR LA HAUTE DIRECTION

Le document intitulé "Tall Oil as Fuel for Mobile Equipment in the Kraft Pulp Industry - Phase II - Part 2" décrit l'évolution des travaux réalisés par la Prince Albert Pulp Company et l'Université de la Saskatchewan (du 1^{er} février 1985 au 28 février 1986) en vue d'évaluer la faisabilité technique de la substitution du tallol valorisé au carburant diesel. On y cherchait surtout à évaluer la résistance du moteur à très long terme.

L'étude indique que le circuit d'injection du carburant s'use plus rapidement lorsque le mélange de carburant contient du tallol. Les systèmes d'injection de carburant lâchaient systématiquement après 300 à 400 heures de fonctionnement. Cette défaillance résulte de la combinaison d'un encrassement au carbone, qui se dépose dans l'aiguille d'injection, et de la corrosion des ouvertures de l'injecteur. Ce problème d'injection semble causer une usure et une corrosion du moteur plus élevées que la normale et accroître l'accumulation des dépôts dans la chambre de combustion. La principale cause de l'usure et de la corrosion des cousinets semble être une dégradation de l'huile lubrifiante attribuable à la contamination produite par le carburant. L'accumulation de dépôts dans la chambre de combustion était vraisemblablement causée par le carburant. Bien qu'elle n'ait pas influée directement sur le rendement du moteur pendant la durée des essais (jusqu'à 1 570 heures), une accumulation continue provoquerait une usure excessive des pistons, des joints circulaires et des cylindres. Ces deux problèmes, estime-t-on, proviennent de l'accumulation de dépôts et des pannes du système d'injection.

Étant donné le régime actuel de tarification, les carburants au tallol ne sont pas économiquement rentables. Bien que le coût du tallol brut soit d'environ le tiers ou la moitié de celui du carburant diesel, les frais inhérents de traitement et de distribution et le coût accru d'entretien du moteur éliminent cet avantage. Cependant, si la production de tallol déshydraté comme carburant était intégrée au fractionnement du tallol destiné aux marchés classiques, ce produit pourrait présenter un avantage économique. Par ailleurs, la vente des acides gras du tallol est souvent le facteur qui restreint la production des usines de fractionnement. La création d'un autre débouché pour cette substance pourrait s'avérer fort précieuse.

En vue de répondre à ces besoins futurs, il faudrait entreprendre une autre étude de la faisabilité technique de l'intégration des acides gras du tallol dans les mélanges carburants. Dans un premier temps, cette étude devrait viser la réduction de la corrosion et de la formation de dépôts dans le système d'injection. On pourrait y arriver en ajoutant des additifs ou en réduisant la concentration des acides gras dans le mélange d'essence. D'autres solutions pourraient également se dégager de l'étude. On croit que les difficultés reliées à l'injection de carburant sont la principale cause de la dégradation des huiles lubrifiantes et de la formation de dépôts dans la chambre de combustion. Par conséquent, si ces problèmes sont résolus, les autres le seront également.

TABLE OF CONTENTS

		PAGE
	ACKNOWLEDGMENTS	i
	EXECUTIVE SUMMARY – RÉSUMÉ	ii
	TABLE OF CONTENTS	iv
	LIST OF APPENDICES	v
	LIST OF TABLES	v
	LIST OF FIGURES	vi
I	INTRODUCTION	
	- PRIOR ART:	1
	- CONCLUSIONS FROM PHASE I:	5
	- CONCLUSIONS FROM PHASE II:	7
II	TESTING PROCEDURES	
	- PREPARATION OF FUELS:	11
	1. DIESEL	11
	2. DEWATERED TALL OIL/DIESEL FUEL BLEND	12
	3. TALL OIL FATTY ACID/DIESEL FUEL BLEND	15
	- ENGINE TESTING:	18
	- PHYSICAL AND CHEMICAL ANALYSIS OF THE FUEL BLENDS:	20
	- CRANKCASE OIL ANALYSIS:	21
	- CORROSION TESTING:	22
III	RESULTS AND DISCUSSION	
	- ENGINE TESTS:	23
	1. DEWATERED TALL OIL FUEL BLEND	23
	2. TALL OIL FATTY ACID FUEL BLEND	27
IV	CONCLUSIONS	30
V	RECOMMENDATIONS	35
VI	REFERENCES	36

APPENDICES

APPENDIX I	Fuel Blend Nomenclature
APPENDIX II	Physical and Chemical Analysis of the Fuel Blends
APPENDIX III	Engine Test Results (Dewatered Tall Oil)
APPENDIX IV	Inspection of Fuel Injector Plunger Corrosion
APPENDIX V	Engine Test Results (Tall Oil Fatty Acids)

LIST OF TABLES

		Page No.
TABLE 1	Composition of Dewatered Tall Oil	15
TABLE 2	Composition of Tall Oil Fatty Acids	16
TABLE 3	Summary of Fuel Characterization Tests	20
TABLE 4	Crankcase Oil Analysis	21

LIST OF FIGURES

		Page No.
FIGURE 1	Soap Collection and Tall Oil Production	3
FIGURE 2	Typical Composition of Canadian CTO	4
FIGURE 3	Tall Oil Upgrading By Distillation	13
FIGURE 4	Distillation Curves	14
FIGURE 5	Fuel Delivery System Schematic	17
FIGURE 6	Deutz Model F2L 912 - Instrumentation Layout	19

I - INTRODUCTION

This report outlines the developments of the work performed by Prince Albert Pulp Company and the University of Saskatchewan (from February 1, 1985 to February 28, 1986) in the course of assessing the technical feasibility of using upgraded tall oil as a diesel alternative for the operation of mobile equipment. It is intended to be supplementary to the final report of ENFOR project C390, entitled TALL OIL AS FUEL FOR MOBILE EQUIPMENT IN THE KRAFT PULP INDUSTRY (R. J. Secor, L. A. Lewko, W. B. Reed: submitted to Energy Mines and Resources, Ottawa, Canada, March 31, 1984: ref 1) and to the final report entitled TALL OIL AS FUEL FOR MOBILE EQUIPMENT IN THE KRAFT PULP INDUSTRY - PHASE II (R.J. Secor, W.B. Reed, L.A. Lewko: submitted to E.M.R., Ottawa, Canada, February 15, 1985: ref 2).

PRIOR ART:

Tall oil soap is a byproduct of kraft pulping. During the pulping operation, fatty and rosin acids produced in the tree are saponified by the pulping (white) liquor. The soap is washed from the pulp in brown stock washers, and is carried with the black liquor to the evaporators. Soap can then be recovered from partially evaporated black liquor and reacted with acid to yield crude tall oil, lignin and spent acid. The crude tall oil may then be separated from the lignin and spent acid by means of gravity or centrifugal separation. The precipitated lignin and spent acid is then neutralized and returned to the mill's recovery system. Figure 1 shows a simplified system schematic for the collection of soap and the production of crude tall oil.

In some mills, tall oil soap is left in the spent pulping liquor and its heating value is recovered by burning it in the recovery furnace. Unlike soap, crude tall oil can be burned for energy in a greater range of process equipment.

In situations of fluctuating market demand for tall oil, it is highly desirable for a mill to have other profitable uses for tall oil. Moreover, if tall oil could be adapted for use in mobile diesel equipment, a pulp mill may be able to achieve a high degree of energy self-sufficiency for its woodlands operations.

Tall oil and tall oil derivatives have been cited to be useful as additives to inhibit corrosion in diesel fuel, kerosine and gasoline (ref 3 and 4). In its use as a fuel, Wernersson (ref 5) reported the successful substitution of crude tall oil (up to 60%) for heavy fuel oil for the operation of a lime kiln in a Swedish kraft pulp mill. In the Scandinavian market, this mill's crude tall oil could only command a price that was equivalent to 30% of the prevailing price of heavy fuel oil. Indeed, several other Swedish and Canadian mills often burn tall oil to reduce their external purchases of conventional fuel oil. What was not known prior to this study was how tall oil would perform as fuel for the operation of mobile diesel equipment. Figure 2 shows the typical composition of Canadian crude tall oil.

Figure 1: Soap Collection and Tall Oil Production

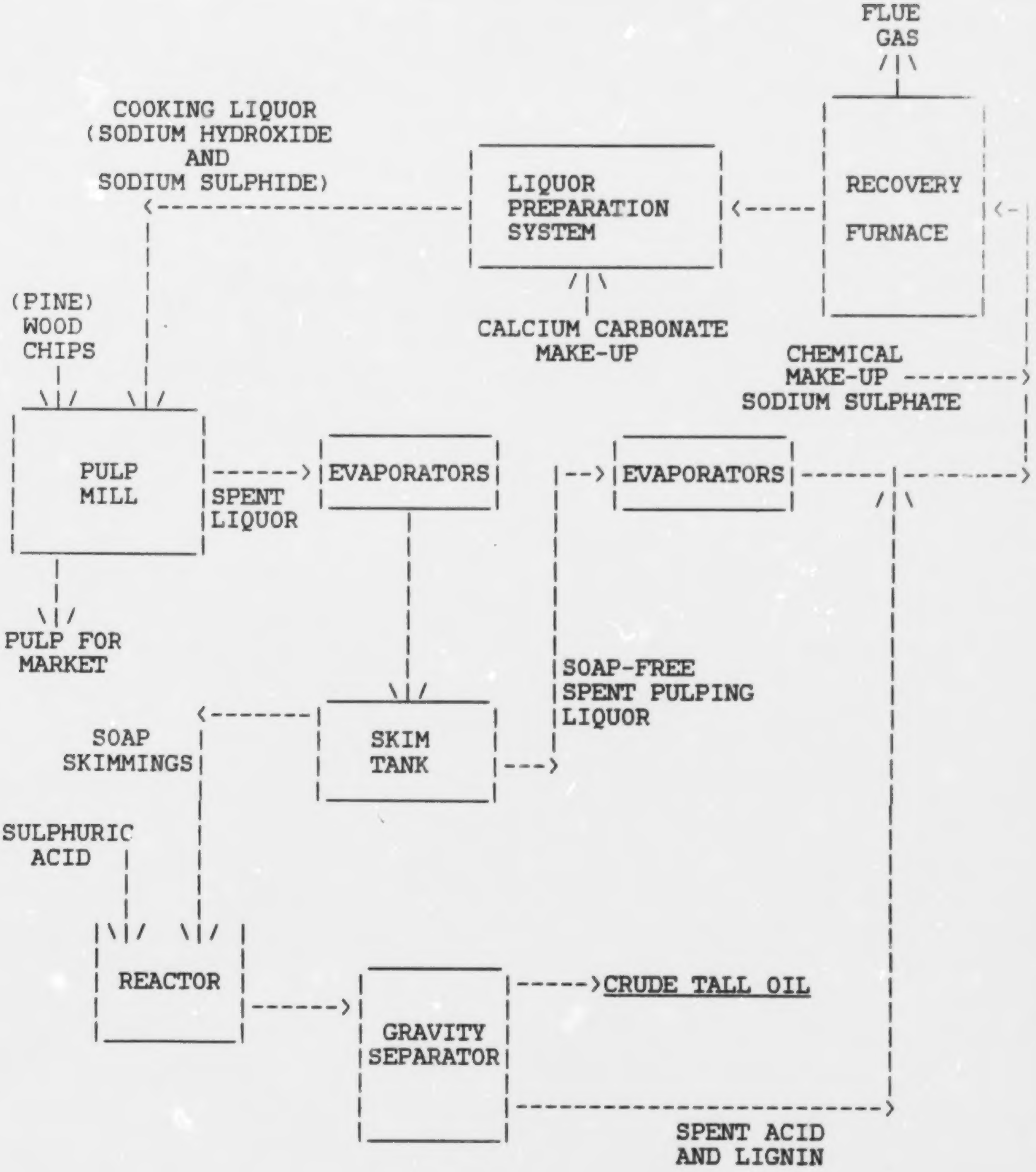
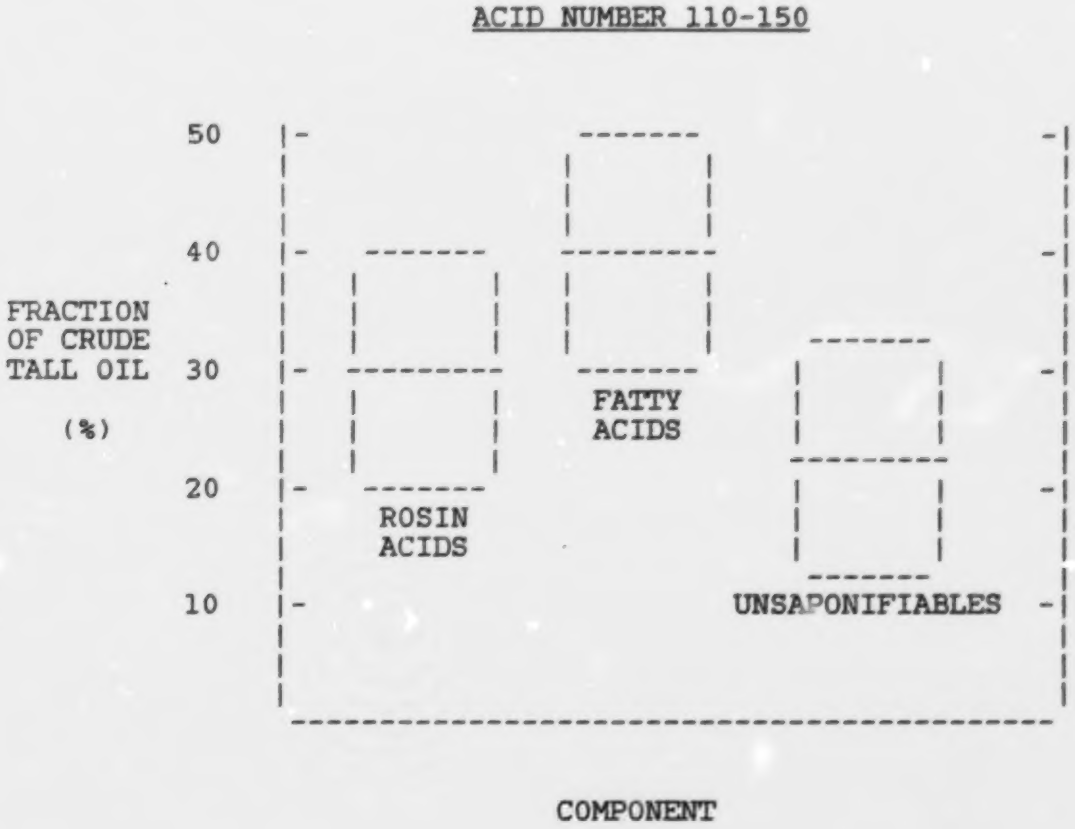

FLUE GAS
COOKING LIQUOR (SODIUM HYDROXIDE AND SODIUM SULPHIDE)
LIQUOR PREPARATION SYSTEM
RECOVERY FURNACE
(PINE) WOOD CHIPS
CALCIUM CARBONATE MAKE-UP
CHEMICAL MAKE-UP SODIUM SULPHATE
PULP MILL
EVAPORATORS
SPENT LIQUOR
EVAPORATORS
PULP FOR MARKET
SOAP-FREE SPENT PULPING LIQUOR
SOAP SKIMMINGS
SKIM TANK
SULPHURIC ACID
REACTOR
CRUDE TALL OIL
GRAVITY SEPARATOR
SPENT ACID AND LIGNIN

Figure 2: Typical Composition of Canadian Crude Tall Oil



CONCLUSIONS FROM PHASE I:

In the report entitled TALL OIL AS FUEL FOR MOBILE EQUIPMENT IN THE KRAFT PULP INDUSTRY (ref 1) the following conclusions were tabled:

1.) Crude tall oil (CTO) (*) blended 50/50 with conventional diesel was used successfully in a diesel engine. A two cylinder direct injection diesel engine ran for over 400 hours on various blends of diesel and CTO.

2.) Six grades of crude tall oil from three producing regions in Canada were tested. These oils ranged in acid number from 118.1 to 142.8. The acid number of the CTO appears to have no effect on overall engine performance.

3.) Depitched tall oil, blended with diesel, was also used to fuel the two cylinder test engine. Two grades of depitched tall oil were used (acid number 157.0 and 164.0). As with crude tall oil, no appreciable difference in engine performance was found between the two depitched oils. In all, the engine was operated for 110 hours using the depitched tall oil and diesel fuel blends.

4.) Compared to conventional diesel, the tall oil fuel blends show an increase of 5-15% in specific fuel consumption. This is offset by a corresponding increase in maximum power.

(*)NOTE: A glossary of fuel blend nomenclature can be found in Appendix I.

5.) No increase in engine wear was found when operating on the tall oil/diesel fuel blends. However, the tall oil/diesel/methanol fuel blends showed considerable wear in the combustion chamber and on the pistons and cylinders. As well, operating with the tall oil/diesel/methanol and the depitched tall oil/diesel fuel blends resulted in injector failure.

6.) A severe increase in fuel injection pump wear was found. When using the crude tall oil/diesel fuel blends the injection pump life was decreased to 100-150 hours. The life of the fuel injection pump was shortened to as little as 40 hours when using fuel blends containing depitched tall oil. Normal operating conditions should allow for a fuel injection pump life of at least 3000-4000 hours.

7.) No evidence of an increase in fuel related engine deposits was found on the pistons, cylinders, valves, or rings. A buildup of a soft black deposit was found on the injector tips, but this did not affect the spray pattern or nozzle performance. By comparison, in reports by various authors (ref 6), vegetable oil fuels presented serious problems with engine deposits. Fouling of injectors, rings and valves was reported to have occurred after as little as 30 hours of operation.

8.) Analyses of the fuel blends have shown that blends of 50% crude tall oil and 50% diesel fuel have pour points near -40°C. This was unexpected since pure CTO has a very high viscosity and a pour point near 15°C. This low pour point might allow for winter operations. Vegetable oils were reported to have pour points near 0°C (ref 6,7).

9.) Analysis of the used crankcase oil showed that its viscosity increased from a 30 weight oil to that of a 40 weight oil. It is not clear if this unusual increase in viscosity can be directly attributed to the tall oil fuels.

CONCLUSIONS FROM PHASE II:

In the report entitled TALL OIL AS FUEL FOR MOBILE EQUIPMENT IN THE KRAFT PULP INDUSTRY - PHASE II (ref 2) the following conclusions were tabled:

1.) Crude tall oil, blended 50/50 with diesel, performs well with regard to general short term engine performance. However, the long term engine life is severely shortened when crude tall oil is used in the fuel. The most noticeable deterioration occurred in the fuel injection system. In the Deutz engine, the fuel injection pump lasted for only 120 hours before maintenance was required. In the Detroit Diesel engine, deterioration of the fuel injectors occurred even more rapidly. This resulted in a drop in engine performance after as little as 15 hours.

2.) General short term engine performance is considered to be satisfactory when a blend of 50% dewatered tall oil and 50% diesel is used to fuel the Deutz engine. Engine starting, at ambient temperatures below 5°C, is more difficult with the blend than with diesel alone.

3.) The specific fuel consumption of the Deutz engine is 10-11% higher for the tall oil fuels than for straight diesel. The maximum power output of the Deutz engine is slightly higher when fuels containing dewatered tall oil were used.

4.) Initially, the specific fuel consumption of the Detroit Diesel engine was 7% higher with the crude tall oil fuel than with conventional diesel. Over the duration of the test (205 hours) the fuel consumption increased by 21%. This increase in fuel consumption was likely due to the continual deterioration of the fuel injectors caused by the crude tall oil fuel.

5.) Fuel filter life is shortened when the tall oil fuels were used. However, the dewatered tall oil fuel is much better than the crude tall oil fuel in this respect.

6.) The dewatered tall oil fuel allows for a much longer fuel injection pump life than the crude tall oil fuels. This is substantiated by longer service intervals, and much less corrosion pitting evident on the pump plungers. The service life of the fuel injection pump was the major technical concern arising from phase I of this study.

7.) A major difficulty encountered with the tall oil fuels is lubrication failure resulting in increased wear of the engine bearings, crankshaft, and camshaft. This was evident in both the Deutz and Detroit Diesel engines.

8.) Another major difficulty is a buildup of hard fuel deposits on the piston surfaces. This was more severe in the Detroit Diesel engine than the Deutz engine and had resulted in scoring of the Detroit Diesel's pistons and cylinders. In both cases, the amount of deposits was felt to be unacceptable. These deposits may have resulted from incomplete combustion of the heavier materials in the tall oil.

9.) Analyses of the used crankcase oils showed that, in most instances, the amount of wear metals present was higher than normal. The viscosity of the oil increased rapidly over time when the tall oil fuels were used.

10.) The dewatered tall oil fuel results in higher particulate loading, and decreased nitrogen oxides loading than conventional diesel. There is no appreciable difference in sulphur dioxide loading between the two fuels.

11.) Under the current price structure there is no economic advantage to replacing diesel with the tall oil fuels. This is a combined result of the higher specific fuel consumption, processing costs, processing losses, distribution costs, and increased engine maintenance costs resulting from the tall oil fuels. This situation may be changed if the dewatering process was incorporated with an in situ tall oil fractionation plant. Moreover, tall oil fractionators are often limited by their ability to find markets for the fatty acid fraction. Tall oil fatty acid fuels may offer an alternative to the conventional markets for this product, which in turn could increase the profitability of the fractionation plant. Tall oil fatty acid fuels would likely present fewer engine operating problems due to the absence of the pitch and rosin acids.

II - TESTING PROCEDURES

The purpose of this project was to assess the technical feasibility of using tall oil, in its crude or upgraded form, as a diesel substitute for the operation of mobile equipment. In phase II, emphasis was placed on assessing engine endurance over the longer term and developing a means to increase the service life of the fuel injection system. In phase II - part II, the emphasis was also put on long term engine endurance, specifically using upgraded tall oil fuels to confirm that dewatered tall oil substantially reduces fuel injection pump corrosion.

PREPARATION OF FUELS:

In order to further evaluate the potential of using tall oil as a diesel alternative, the following fuel blends were prepared and tested.

1.) DIESEL - After each engine rebuild, the engines were "broken-in" using 100% conventional diesel. As well, diesel was used in all of the tall oil fuel blends. This diesel was obtained from Federated Co-operatives Limited. Both winter and summer grade diesels were used depending on the seasonal availability.

2.) DEWATERED TALL OIL/DIESEL FUEL BLENDS - The crude tall oil/diesel fuel blends have initial boiling points significantly below that for conventional diesel. Winter grade diesel has an initial boiling point near 155°C. In comparison, the initial boiling point for a blend of 50% crude tall oil and 50% winter grade diesel is near 100°C. Since it is felt that the initial boiling point (ie. the lower boiling point materials) has an effect on injection pump corrosion, the crude tall oil was dewatered. This resulted in the removal of the water and light boiling fractions (heads) from the crude tall oil. Figure 3 shows the 4 major component groups of crude tall oil, and their relative position in the drawing is indicative of their boiling point range. Dewatering was performed using a thin film evaporator operated at elevated temperature and reduced pressure, such that the initial boiling point of the dewatered tall oil was near 160°C. This required the removal of 3-6% of the crude tall oil. The resulting dewatered tall oil (the composition is shown in Table 1) was blended with diesel in 50/50 proportions, and heat treated in accordance with the procedure developed in Phase I (ref 1). Figure 4 shows typical distillation curves for conventional diesel, a blend of crude tall oil and diesel, a blend of dewatered tall oil and diesel and a blend of tall oil fatty acids and diesel.

Figure 3 Tall Oil Upgrading By Distillation

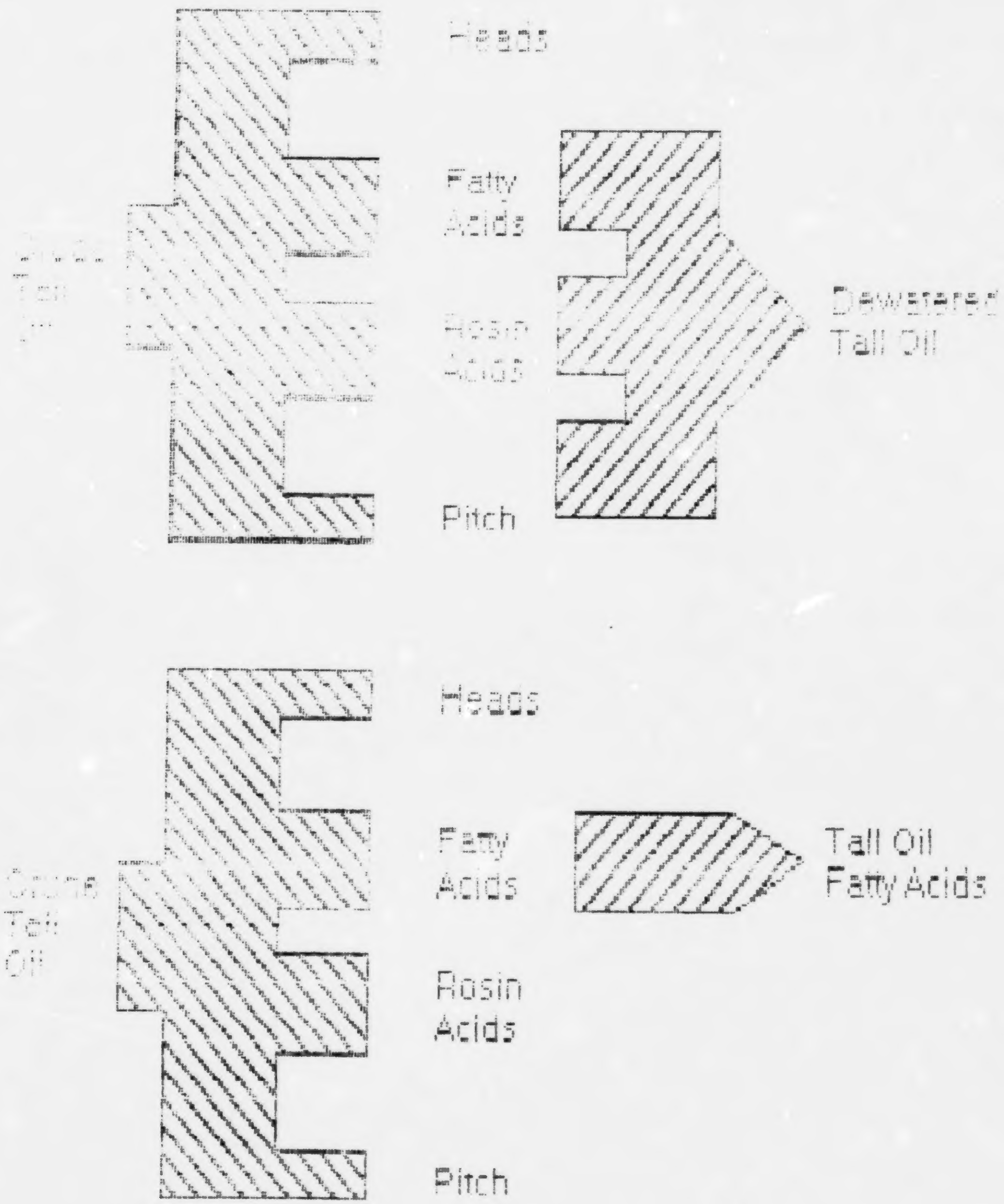

Heads
Fatty Acids
Crude Tall Oil
Rosin Acids
Pitch
Dewatered Tall Oil
Heads
Fatty Acids
Crude Tall Oil
Rosin Acids
Pitch
Tall Oil Fatty Acids

Figure 4: Distillation Curves

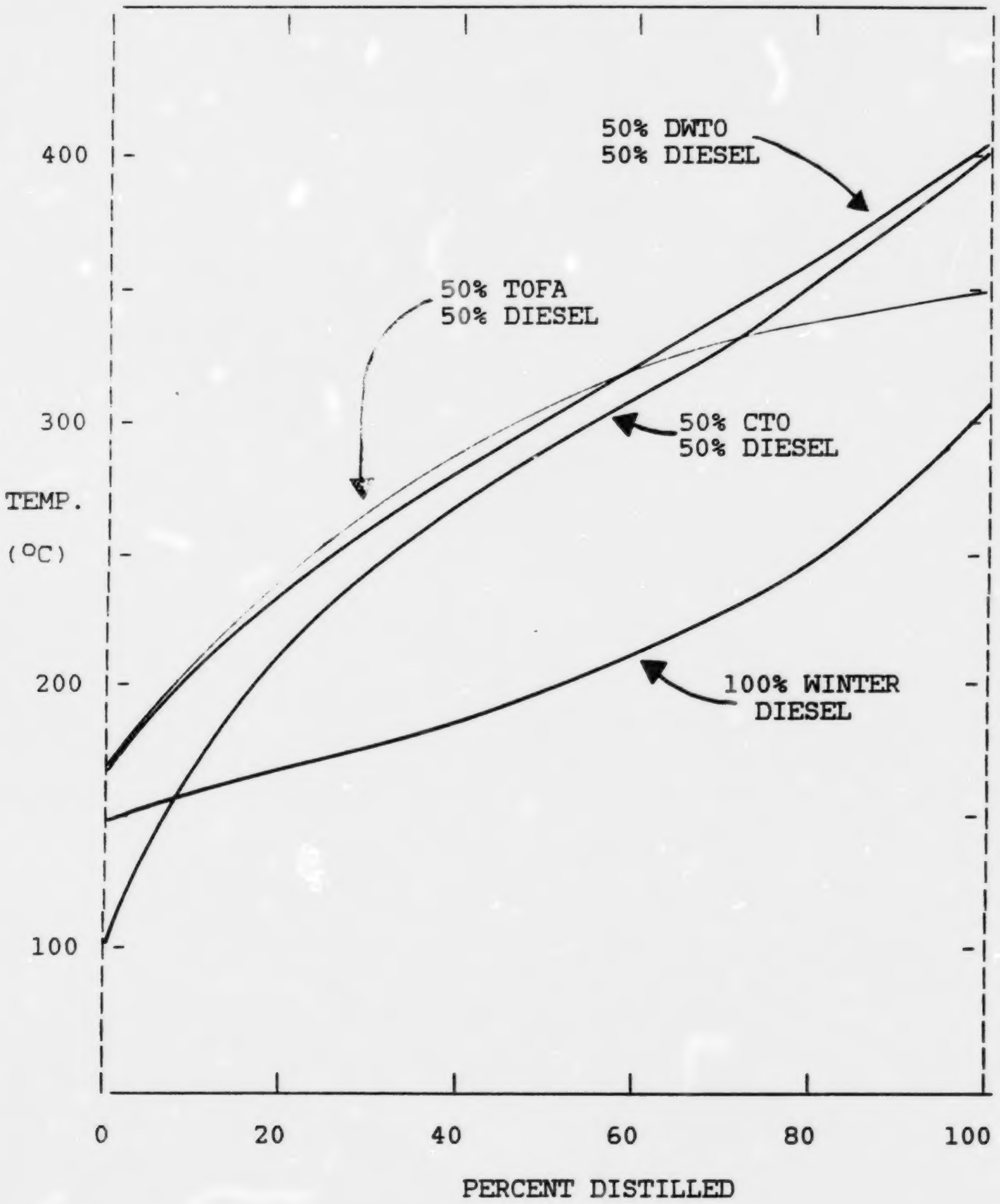


Table 1: Composition of Dewatered Tall Oil

Parameter	Range
Fatty Acids	36-38%
Rosin Acids	39-41%
Unsaponifiables	24-26%
Acid Number	145-147
Water	0%

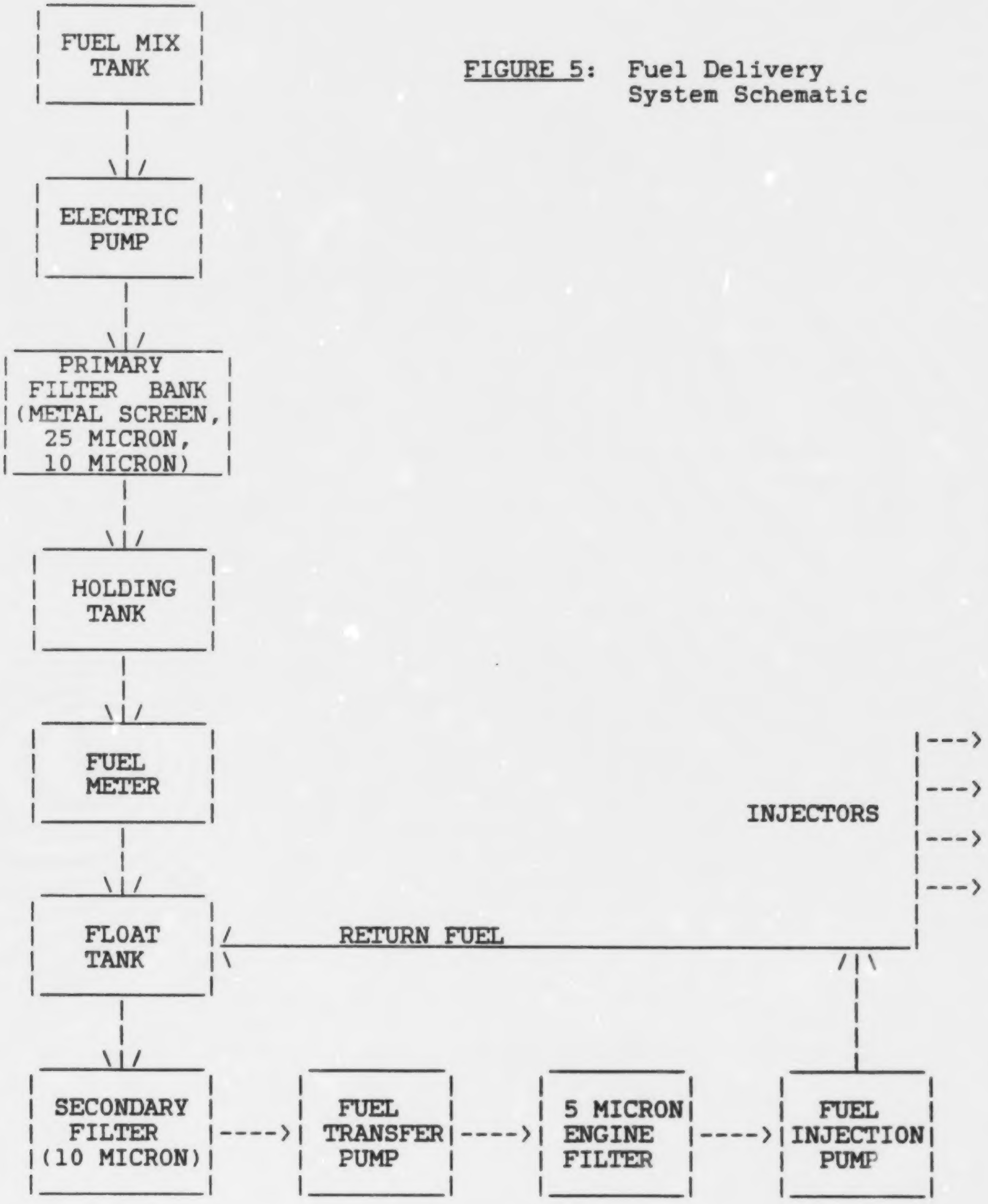
3.) TALL OIL FATTY ACIDS (TOFA)/DIESEL FUEL BLENDS - TOFA is obtained by removing both the lighter and the higher boiling point materials from crude tall oil by distillation. Each of the 4 groups of components shown in Figure 3 is made up of several different compounds, each with a different boiling point, so it is very difficult to get a clean separation of these fractions, even with many stages of distillation. The initial part of the distillation curve is very similar to dewatered tall oil/diesel, but the final boiling point is much lower because the heavier materials (lignin, pitch, rosin acids, etc.) have been removed. Some experimentation was performed on a thin film evaporator to produce TOFA, but because of the large quantities required for long term engine tests, and because of the poor separation obtained with only 1 stage of distillation in the thin film evaporator, the majority was obtained from the Hercules Canada Inc. refinery in Burlington, Ontario. The composition is given in Table 2. The yield of TOFA from CTO is typically 30-40%. This TOFA was blended with diesel in 50/50 mixtures. Since all the heavier materials were removed, there was no problem with suspended solids, so the heat treatment process was unnecessary.

Table 2: Composition of Tall Oil Fatty Acids

Parameter	Range
Fatty Acids	89-95%
Rosin Acids	2-5%
Unsaponifiables	2-4%
Acid Number	187-192
Water	0%

Each fuel blend was mixed as required and delivered to the engine through the series of filters shown in figure 5.

FIGURE 5: Fuel Delivery System Schematic


FUEL MIX TANK
ELECTRIC PUMP
PRIMARY FILTER BANK (METAL SCREEN, 25 MICRON, 10 MICRON)
HOLDING TANK
FUEL METER
FLOAT TANK
RETURN FUEL
INJECTORS
SECONDARY FILTER (10 MICRON)
FUEL TRANSFER PUMP
5 MICRON ENGINE FILTER
FUEL INJECTION PUMP

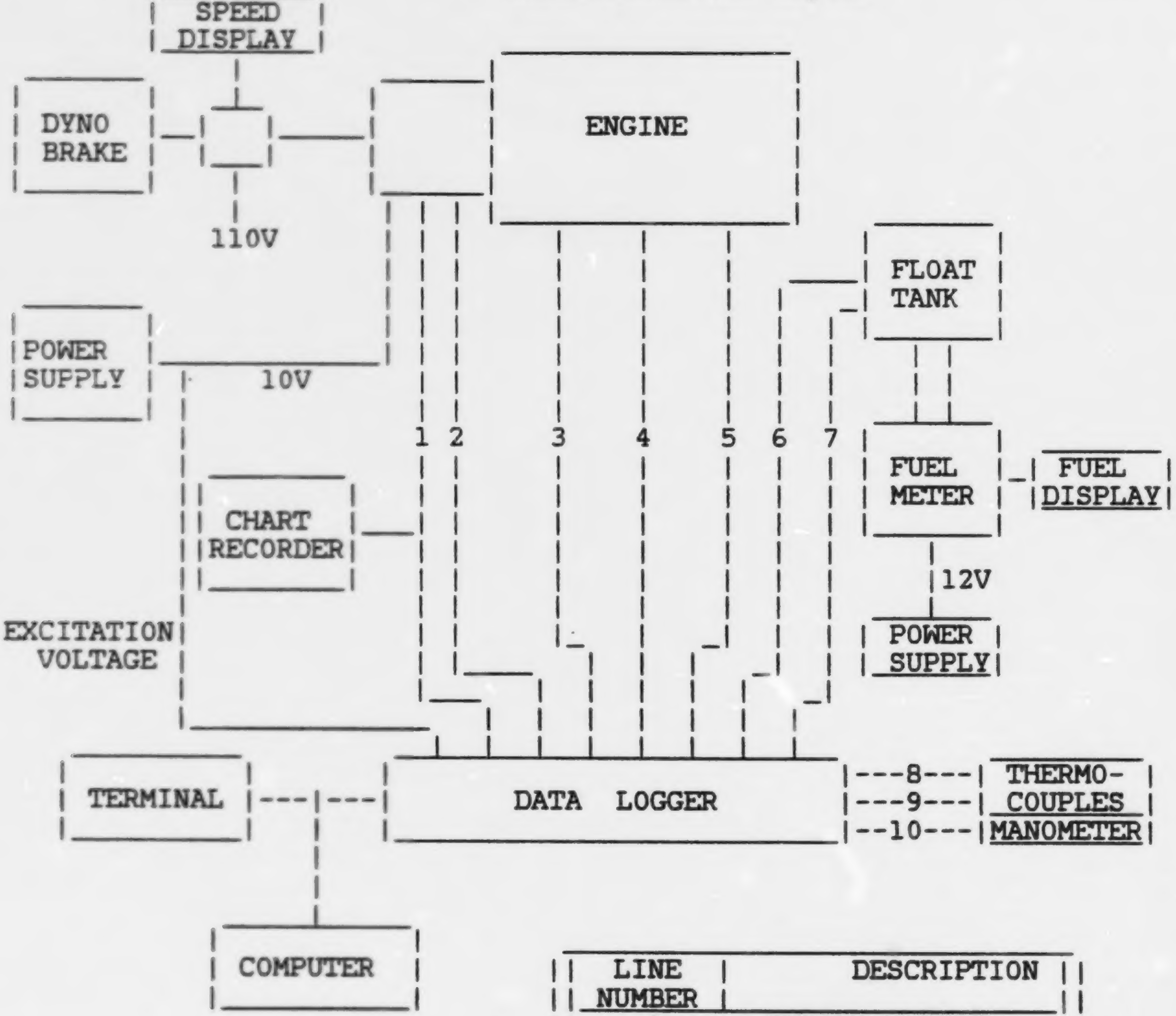
ENGINE TESTING:

All engine testing was performed on a 25kW air cooled, direct injection, Deutz model F2L 912 diesel engine. Figure 6 shows the instrumentation layout. As shown, the fuel consumption, engine speed and torque, and various temperatures were monitored.

The testing program consisted of 2 major long term tests. The first involved a 100 hour break in period using 100% summer grade diesel and a 580 hour test with a blend of 50% dewatered tall oil and 50% diesel (387 hours on winter grade diesel and 193 hours on summer grade diesel). The second long term test involved a 100 hour break in using 100% summer grade diesel and a 1570 hour test using a blend of 50% tall oil fatty acids and 50% summer grade diesel.

The fuel injectors were serviced as required. Crankcase oil samples were taken at 20 hour intervals during each of the tests, and were analyzed at Federated Co-operative Refineries Limited for wear metals and lubricant additives content. After each long term test, the engine was completely disassembled, inspected for signs of wear or corrosion, and subsequently rebuilt. During the second long term run, on the fatty acid fuel blend, the pistons, cylinders and rings were replaced, after 420 hours on the fatty acid fuel blend or 520 hours after the rebuild, because the rings had failed to seat and were causing

Figure 6: Deutz Model F2L 912 - Instrumentation Layout


SPEED DISPLAY
DYNO BRAKE
ENGINE
110V
POWER SUPPLY
10V
FLOAT TANK
1
2
3
4
5
6
7
FUEL METER
FUEL DISPLAY
CHART RECORDER
12V
POWER SUPPLY
EXCITATION VOLTAGE
TERMINAL
DATA LOGGER
8
9
10
THERMO- COUPLES
MANOMETER
COMPUTER

LINE NUMBER	DESCRIPTION
1	ENGINE TORQUE
2	ENGINE SPEED
3	EXHAUST TEMP.
4	BLOCK TEMP.
5	CRANKCASE TEMP.
6	FUEL TEMP.
7	FUEL FLOW
8	AIR TEMP. (W.B.)
9	AIR TEMP. (D.B.)
10	ATMOS. PRESSURE

excessive lubrication oil consumption. This problem happens occasionally and was not attributed in any way to the fuel. The engine test reports are attached in appendices III and V and show numerous photographs of engine parts during the post trial inspections.

PHYSICAL AND CHEMICAL ANALYSIS OF THE FUEL BLENDS:

Each of the fuel blends described in the previous section, the fuel blends prepared in TALL OIL AS FUEL FOR MOBILE EQUIPMENT IN THE KRAFT PULP INDUSTRY (ref 1) and the fuel blends prepared in TALL OIL AS FUEL FOR MOBILE EQUIPMENT IN THE KRAFT PULP INDUSTRY - PHASE II (ref 2) were analyzed at Alberta Research Council for the series of tests listed in table 3. The results from these tests can be found in appendix II.

Table 3: Summary of Fuel Characterization Tests

Test	Test Method
Flash Point	ASTM D93
Pour Point	ISO 3016
Water and Sediment	ASTM D96
Water	ASTM D95
Sulfur	ASTM D1552
Corrosion	ASTM D130
Distillation	ASTM D86
Heat of Combustion	ASTM D2015
Ash	ASTM D482
Carbon Residue	ASTM D524
Viscosity	ASTM D445
Cloud Point	ASTM D2500

CRANKCASE OIL ANALYSIS:

Samples of the used crankcase oil were taken at regular intervals during the engine testing. These were analyzed at Federated Co-operative Refineries Limited, in Regina, for the wear metals and lubricant additives listed in table 4.

Table 4: Crankcase Oil Analysis

Wear Metals:

Metals	Origin
Aluminum	Bearings and Pistons
Iron	Liner and Crank
Chromium	Rings
Tin	Bearings
Copper	Thrust Bearings
Silicon	Dirt (unless silicon gaskets are used)
Lead	Bearings

Oil Additives:

Additives	Purpose
Barium	Dispersant/detergent
Boron	Coolant
Calcium	Dispersant/Detergent
Magnesium	Corrosion/Anti-wear
Phosphorous	Anti-wear/Pressure Reduction
Sodium	Contaminant
Sulphur	Anti-wear/Pressure Reduction
Zinc	Anti-wear/Pressure Reduction

Other:

Viscosity

The results from these tests, together with recommended levels for each element, are included with the engine test reports and can be found in appendices III (sub appendix D) and V (sub appendix C).

CORROSION TESTING:

It became very evident during phase I of the project, that the service life of the fuel injection pump was severely shortened by the tall oil fuel blends. This was particularly apparent when methanol or depitched tall oil was used in the blends. The service life was reduced to 100-150 hours for blends containing 50% crude tall oil and 50% diesel; to 54 hours for a blend of crude tall oil, methanol, and diesel; and to as short as 40 hours when a blend of depitched tall oil and diesel was used (ref 1). Normal operations should allow for a service life of at least 3000-4000 hours. In phase II of the project, it was determined by Hanson Materials Engineering (Western) Limited, in Edmonton, that corrosion was the cause of the fuel pump failure on CTO fuels and that dewatered tall oil fuels greatly reduced the corrosion. The engine was operated for 472 hours on 50% dewatered tall oil and 50% diesel with only slight signs of corrosion evident on the fuel pump plungers.

Hansen Materials Engineering (Western) Limited was again contracted for assistance in the area of corrosion testing. The results of the fuel pump plunger inspection after the long term run on dewatered tall oil fuel are attached in appendix IV. The results of the inspection of the fuel pump plungers and injectors and of a bearing after the long term run on tall oil fatty acid fuel are included with the engine test report in appendix V (sub appendix E).

III - RESULTS AND DISCUSSION

ENGINE TESTS:

Engine tests were performed at the University of Saskatchewan to assess the effect of the tall oil fuels on engine and engine system endurance. A detailed report of engine performance and related maintenance requirements during the long term test on the dewatered tall oil fuel blend is given in appendix III. A detailed report on the long term test using the tall oil fatty acid fuel blend is given in appendix V. The major findings are summarized as follows:

1.) DEWATERED TALL OIL FUEL BLEND - Dewatered tall oil, blended 50/50 with diesel, performs well in the Deutz engine with regard to general engine performance. The general operation, including starting, exhaust gas temperature and exhaust smoke are all comparable to diesel above 5°C ambient temperature. Engine starting at ambient temperatures between 0°C and 5°C is more difficult with the blend than with diesel alone. Temperatures below 0°C prohibit starting with the dewatered tall oil fuel blend or with diesel alone. This is very similar to the performance obtained with a blend of 50% crude tall oil and 50% diesel or with a blend of 50% dewatered tall oil and 50% diesel in phase II.

Specific fuel consumption tests indicate that the engine uses 10-11% more fuel (per unit of power output) using dewatered tall oil fuels than when using 100% diesel (using either summer grade or winter grade diesel for the mixture and for the baseline does not change this difference as long as the same diesel is compared in each case). The maximum power output of the Deutz engine is about the same whether 100% diesel or the dewatered tall oil fuel blend is used. A summary of the specific fuel consumption tests and of the maximum power tests are given in appendix III (tables 1 and 2). The individual test results are found in sub appendices B and C of appendix III.

Fuel filter life is shortened for fuel blends containing dewatered tall oil, depending on the fuel handling techniques used during the heat treatment process (ref 1). However, the dewatered tall oil fuel blend is much easier to filter than the crude tall oil fuel blends used in the previous trials. The maximum filter life is about 100 hours on the dewatered tall oil fuel blend. As fuel temperatures fall below 25°C, the filtering becomes more difficult.

The dewatered tall oil fuel blend greatly increases the fuel injection pump life over the crude tall oil fuel blends used in previous trials. The injection pump lasted only 100-150 hours when the crude tall oil fuel blends were used. In comparison, the injection pump was performing well after 472 hours (phase II) and 580 hours (current study) with the dewatered tall oil fuel blends. Subsequent inspection of the fuel pump plungers showed only slight corrosion, meaning that the fuel pump will last for a much longer time. The results of this inspection can be found in appendix IV.

The fuel injection nozzles required servicing after 540 hours (440 hours on the dewatered tall oil fuel blend). Although not considered a serious problem in phase I or II, because the fuel injection pump usually failed earlier, it is now evident that this is more serious because the nozzles consistently fail after about 400 hours operation.

Although seen to be a serious problem in phase II, the lubrication failure was less evident during this long term run on the dewatered tall oil fuel blend. After 580 hours of operation, there was no evidence of increased wear or corrosion on any bearings or on the oil pump. However, the camshaft lobes and followers showed more wear and/or corrosion than would normally be expected, although not as severe as on previous trials. Also, the valve stems and guides were worn more than usual, causing slightly excessive oil consumption and carbon build up on the valve surfaces. This means that lubrication failure is still a problem, although not as serious as it was originally thought. The engine wear measurements after the long term run can be found in appendix III, sub appendix A.

Crankcase oil analysis showed that all of the wear metals in oil were below the limit values throughout the trial. These results can be found in appendix III, sub appendix D.

Cylinder, piston and ring wear was not excessive, but hard carbon deposits had built up on the piston's surfaces above the piston (see photographs in appendix III). This buildup had just begun to cause interference and wear between the piston and the cylinder surfaces and continued operation would likely cause engine failure. Also, there was a softer carbon build up on the valve surfaces and stems. The deposits are probably caused by incomplete combustion of the heavy ends of the tall oil or possibly due to the combustion of crankcase oil, although the oil consumption was not unusually high. The unburnt portion of the fuel may also have contaminated the crankcase oil and contributed to lubrication breakdown. The crankcase oil analyses indicated that the oil viscosity changed only slightly over time.

2.) TALL OIL FATTY ACID FUEL BLEND - Tall oil fatty acids, blended 50/50 with diesel, perform well in the Deutz engine with regard to general performance. The general operation, including starting, exhaust gas temperature and exhaust smoke are all comparable to diesel above 0^{o}C ambient temperature. Temperatures below 0^{o}C were not encountered during this trial, which ran from May to October, 1985 so it is unknown how the fuel will perform at colder temperatures. The general performance with the fatty acid fuels is very similar to all previous trials with various tall oil fuels except that the fatty acid can probably be used at lower temperatures than the other tall oil fuels (ie. other tall oil fuels were more difficult to start than diesel below 5^{o}C).

Specific fuel consumption tests showed that the engine uses 11% more fuel (per unit of power output) using tall oil fatty acid fuels than when using 100% diesel. This is very similar to all other trials using various tall oil fuels. About 7% of this difference can be explained by the lower heat of combustion of the tall oil fuels, but the remaining 4% must be caused by a lower engine efficiency. The maximum engine power is about the same for tall oil fatty acid fuels as for 100% diesel. This is similar to previous trials, although for some trials the tall oil fuels were found to produce a higher maximum power. However, this was not found consistently. A summary of the specific fuel consumption and maximum power test results is given in appendix V (tables 1 and 2). The individual test results can be found in appendix V, sub appendices A and B.

Fuel filter life was not a problem during this trial. Although the maximum filter life was not determined, only one fuel filter was necessary for the entire 1570 hours on the tall oil fatty acid fuel. Even operating at lower ambient temperatures (temperatures below 0°C were not encountered during the trial) did not seem to harm the filtering process.

The fuel injection pump was not a problem during the trial. The pump lasted throughout the entire 1570 hour trial with no loss in performance. The post trial inspection (see the inspection report in appendix V, sub appendix E) showed no signs of corrosion and only slight wear on the fuel pump plungers. This is as well as could be expected when operating on 100% diesel.

The fuel injection nozzles required servicing 4 times during this trial. It is evident that 300-400 hours is the maximum life of the fuel injectors when operating on tall oil fuels under these conditions. It is also felt that the fuel injection nozzle failure affects the rest of the engine as shown below.

There is definitely a problem with lubrication breakdown causing increased bearing wear and/or corrosion (see engine wear measurements in appendix V, sub appendix D). Inspection at the end of the trial showed that the valve stems and guides and the camshaft lobes were worn more than usual. The camshaft followers and the connecting rod bearings showed definite signs of pitting corrosion. However, no other bearings or parts of the engine seemed to be affected. The crankcase oil analysis for wear metals indicates that the greatest amount of engine wear/corrosion occurs when the fuel injectors are faulty or fouled, as this probably contaminates the lubrication oil. Near the end of the trial the oil change time was increased from 60 hours to 80 and 90 hours for 2 periods. This substantially increased the wear metal levels in the oil. It seems that 60 hours is the maximum lubrication oil life for tall oil fuels under these conditions as compared to a typical life of 100 hours on diesel.

Engine deposits were generally higher than would be expected on diesel. Initial deposits were from lubricating oil because the rings didn't seat properly. Subsequent deposits are atrributed to the tall oil fatty acid fuels because the deposits were rusty orange in colour and not the characteristic black colour from burning lubrication oil (see photographs in appendix V).

The deposits had just begun to cause piston scuffing. It is felt that the majority of these deposits were caused by the failed fuel injectors.

It should be noted that none of these problems had in any way affected the engine performance at the end of the trial as long as the fuel injectors were serviced when necessary (every 300-400 hours).

IV - CONCLUSIONS

From the results of this and previous studies, the following conclusions are accumulated:

1.) Tall oil fuels, blended 50/50 with diesel, perform well with regard to general short term engine performance. At temperatures above 5°C there is no noticable difference between the tall oil fuels and diesel in terms of ease of starting, exhaust gas temperature and exhaust smoke. At temperatures between 0°C and 5°C, the tall oil fuels generally make the engine more difficult to start, although this does not seem to be the case with the fatty acid fuel. Temperatures below 0°C make the engine difficult to start with either diesel or the tall oil fuels.

2.) The specific fuel consumption of the engine is 10-11% higher for the tall oil fuels than for straight diesel. About 6-7% of this difference can be explained by the lower heat of combustion of the tall oil fuels, but the remaining 4% must be caused by a lower engine efficiency.

3.) The maximum power output of the engine is about the same with the tall oil fuels as it is with 100% diesel. Although it was reported as being higher in earlier reports, this has not been found consistently, and it now seems that the maximum power is about the same as with diesel.

4.) Fuel filter life is shortened when crude tall oil or dewatered tall oil fuels were used. However, the dewatered tall oil is much better than the crude tall oil in this respect. Using the tall oil fatty acid fuel blends creates no additional filtering problems than would be expected with 100% diesel.

5.) The fuel injection pump life is dramatically shortened to 100-150 hours when the crude tall oil fuels are used. This problem is greatly reduced by using the dewatered tall oil fuels. After two long term runs of 472 and 580 hours on the dewatered tall oil fuel blends, the fuel pump was still functioning at 100% capacity with no sign of problems. Subsequent inspection of the fuel pump plungers (the parts that had failed during the crude tall oil fuel runs) showed only slight signs of corrosion, indicating that the pump will last for a much longer period. There is no evidence of fuel pump problems on the tall oil fatty acid fuel. After operating for 1570 hours on the tall oil fatty acid fuel blend, a subsequent inspection of the fuel pump plungers showed no signs of corrosion and only slight signs of wear. This indicates that the fuel pump will last as long with the tall oil fatty acid fuel blend as it will on 100% diesel.

6.) The fuel injectors fail repeatedly and consistently after 300-400 hours of operation on tall oil fuel blends. This failure is a combination of fouling of the tip with carbon deposits and of corrosion around the fuel port holes. This was not a serious problem in earlier trials because the fuel pump usually failed earlier. The fuel injector life would probably have been shorter than 300 hours on crude tall oil fuel blends. The fuel injector failure is felt to be the most serious problem now because it seems to lead to lubrication oil breakdown, as discussed below.

7.) There is a major problem with lubrication oil breakdown causing increased wear/corrosion of several engine parts. The camshaft and connecting rod bearings and the camshaft followers all showed signs of pitting corrosion. The camshaft lobes and valve stems and guides were all worn more than usual. However, several engine parts, such as the crankshaft bearings, pistons, rings, cylinders and oil pump showed no signs of corrosion or excessive wear. The main cause of this lubrication oil breakdown is suspected to be contamination of the lubrication oil by unburnt fuel caused by the fuel injector failure. The lubrication oil analysis showed that the wear metal content increased dramatically as the injectors neared failure.

8.) Another major difficulty is a buildup of hard carbon deposits on the piston surfaces and cylinder walls. Softer deposits were found on the valve stems and faces. These deposits resulted from incomplete combustion of the tall oil, possibly caused by fuel injector failure.

9.) Tall oil fuels are not economically feasible at the present time. An economic study was not done in this part of the project, but the respective prices for diesel and for tall oil have not changed dramatically from the study done in phase II (ref 2), which showed dewatered tall oil to be at an economic disadvantage to diesel. With the added processing costs involved to obtain fatty acids from dewatered tall oil (or crude tall oil), the cost of using fatty acids will be substantially higher than for using dewatered tall oil. However, this situation may be altered if the future price differential between diesel and tall oil were to change. The tall oil price tends to fluctuate greatly because of the change in demand for the product fatty and rosin acid cuts from a fractionation plant. If an alternative use for the fatty acids were developed, it could increase the profitability of the tall oil refinery by making the fatty acid market more stable.

V - RECOMMENDATIONS

Tall oil does not appear to be an economically viable alternative to conventional diesel under the current price structure. However, if the cost of petroleum based fuel rises with respect to the price of crude tall oil, tall oil based fuels may become more viable. As well, with the constantly changing markets for tall oil fractionators, it becomes important to develop alternatives to the conventional uses for tall oil and tall oil components.

In an effort to meet these future needs, further study on the technical feasibility of using tall oil fatty acids in the fuel blends should be undertaken. This study should initially concentrate on the reduction of fuel injector corrosion and deposit formation. This may be done by trying fuel additives or by reducing the concentration of the tall oil fatty acids in the fuel blend. Other alternatives may be discovered as the study proceeds. It is felt that the fuel injector problems are the major cause of the lubrication oil breakdown and the deposit formation in the combustion chamber, and that if the injector problems are solved, the other problems will be solved as well.

VI - REFERENCES

1.) Secor, R.J., Lewko, L.A., Reed, W.B., TALL OIL AS FUEL FOR MOBILE EQUIPMENT IN THE KRAFT PULP INDUSTRY, Final Report for ENFOR Project C390, Energy, Mines and Resources, Canada, March 31, 1984.

2.) Secor, R.J., Reed, W.B., Lewko, L.A., TALL OIL AS FUEL FOR MOBILE EQUIPMENT IN THE KRAFT PULP INDUSTRY - PHASE II, Final Report for Energy, Mines and Resources, Canada, February 15, 1985.

3.) Eckert, G.W., FUEL COMPOSITION, Canadian Patent 914,411, November 14, 1972 (Assignee, Texaco Development Corporation, New York).

4.) White, R.V., SULFATE PROCESS TALL OIL AS A RUST INHIBITER FOR FUEL FRACTIONS OF MINERAL OIL, U.S. Patent 2,686,713, August 17, 1954.

5.) Wernersson, L.E., FIRING OF SOAP IN A SODA PLANT, Soda Works Conference, Stockholm, Sweden, November 29, 1979.

6.) American Society of Agricultural Engineers, VEGETABLE OIL FUELS, Proceedings of the International Conference on Plant and Vegetable Oils as Fuels, August, 1982.

7.) Zoerb, G., Blake, J., Craig, W., and Strayer, R., CANOLA OIL AS FUEL FOR FARM DIESEL ENGINES - PHASE II, Final Report, Engineering and Statistical Research Institute Report of Contract File #23 SU.01843-1-EL05, Agriculture Canada, Ottawa, Ontario, 1983.

APPENDIX I

FUEL BLEND NOMENCLATURE

The following is a summary of the nomenclature used to identify the various fuel blends used during this study.

Crude tall oil, or CTO	denotes tall oil which has been produced by acidulation of tall oil soap, as per the process outlined in the "Prior Art" section.
Depitched tall oil, or DPTO	denotes tall oil which has had the heavy ends (pitch) removed.
Dewatered tall oil, or DWTO	denotes tall oil which has had its water and light boiling fractions removed as per the process outlined on page 11.
Tall oil fatty acids, or TOFA	denotes tall oil which has been distilled to remove both the light and the heavy boiling fractions as per the process outlined on page 12.
Crude tall oil/diesel fuel blend, or crude tall oil fuel	denotes a blend of crude tall oil and conventional diesel
Dewatered tall oil/diesel fuel blend, or dewatered tall oil fuel	denotes a blend of dewatered tall oil and conventional diesel
Tall oil fatty acid/ diesel fuel blend, or tall oil fatty acid fuel	denotes a blend of tall oil fatty acids and conventional diesel
Tall oil/diesel fuel blend, or tall oil fuel	denotes a fuel blend of conventional diesel and either crude or upgraded tall oil. Upgraded tall oil could refer to any fraction of crude tall oil, but in this report it refers to dewatered tall oil or tall oil fatty acids.

NOTE: Although it may not be explicitly stated, all of the fuels used during the engine tests contain some amount of conventional diesel.

APPENDIX II

PHYSICAL AND CHEMICAL PROPERTIES

OF THE FUEL BLENDS

The following is a tabulation of the results obtained from the analyses performed by Alberta Research Council. These tables include results from fuel blends produced during phase I, phase II and phase II - part II of this study.

The following abreviations are used to describe the fuel components.

Code	Description
CTOA	crude tall oil from Great Lakes Forest Products Ltd. (Thunder Bay, Ont.) "winter grade"
CTOB	crude tall oil from B. C. Chemicals Ltd. (Prince George, B.C.) "winter grade"
CTOC	crude tall oil produced from Prince Albert Pulp Co.'s tall oil soap, using pilot plant equipment "winter grade"
CTOD	crude tall oil from Great Lakes Forest Products Ltd. (Thunder Bay, Ont.) "summer grade"
CTOE	crude tall oil from B. C. Chemicals Ltd. (Prince George, B.C.) "summer grade"
CTOF	crude tall oil produced from Prince Albert Pulp Co.'s tall oil soap, using pilot plant equipment "summer grade"

Code	Description
CTOP	crude tall oil from Prince Albert Pulp Co. Ltd.'s CTO plant (Prince Albert, Sask.)
CTOPE	CTOP esterified with methanol
DWTO	dewatered tall oil
DPTO	depitched tall oil
DPDW	depitched and dewatered tall oil
TOFA	tall oil fatty acids
WDSL	winter grade diesel fuel
SDSL	summer grade diesel fuel
METH	reagent grade methanol
TOFA-C4 or TO-4	TOFA obtained from the Hercules Canada Inc. refinery in Burlington, Ontario; brand name PAMAK-C4.
TOFA-2 or TO-2	TOFA obtained from a Bergvik Kemi AB refinery in Soderhamn, Sweden; brand name TO 2.

LABORATORY SAMPLE NUMBER	2104-83G	1651-83G	2105-83G	XXXXXXXX	83-	1690-83G	1652-83G	2106-83G
REFERENCE COMPOSITION	DIESEL B WINTER DIESEL	WINTER DIESEL	DIESEL C SUMMER DIESEL	CTOA	000523 CTOA (SASK-OIL)	CTOB	CTOC	CTOD
FLASH POINT (C)	51	48	51	91	120	184	202	224
POUR POINT (C)	-39	-45	-27	15	10	0	15	12
WATER AND SEDIMENT (vol.%)	XXXXXXXX	0	0	4	2.8	1.1	1.4	1.8
WATER (vol.%)	XXXXXXXX	0.05	0	1.2	1.6	0.8	1.5	1.6
SULFUR (wt.%)	XXXXXXXX	0.17	0.23	0.19	0.17	0.15	0.24	0.33
CORROSION	XXXXXXXX	1a	1a	4c	4c	4c	4c	4c
HEAT OF COMBUSTION (MJ/kg)	XXXXXXXX	45.13	45.07	38.9	39	38.81	38.22	38.56
ASH (wt.%)	XXXXXXXX	0.01	0.01	0.05	0.04	0.06	0.03	0.05
CARBON RESIDUE (wt.%)	XXXXXXXX	0.19	0.4	0.72	0.74	0.85	0.76	0.85
VISCOSITY (cSt)								
@-20 C	5.775	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
@ 0 C	3.207	XXXXXXXX	5.171	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
@20 C	2.091	2.066	3.096	2030	XXXXXXXX	1420	NOTE 3	XXXXXXXX
@40 C	1.493	1.486	2.084	310	260	284.8	423.6	582.5
@70 C	XXXXXXXX	1.008	1.323	51.8	XXXXXXXX	53.44	65.61	75.29
@90 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	29.83
DISTILLATION RANGE (C)								
INITIAL B.P.	XXXXXXXX	156.5	XXXXXXXX	108	105	102.5	100	99
10%	XXXXXXXX	178.5	XXXXXXXX	163.5	307	308.5	289	101
50%	XXXXXXXX	216	XXXXXXXX	330.5	361	342.5	353.5	350.5
90%	XXXXXXXX	268	XXXXXXXX	XXXXXXXX	377	367.5	379.5	378
END POINT	XXXXXXXX	301.5	XXXXXXXX	XXXXXXXX	377	368.5	381.5	378

NOTE 1: ROSIN ACIDS CRYSTALLIZING
NOTE 2: SAMPLE SOLID AT THIS TEMPERATURE
NOTE 3: SAMPLE TOO VISCOUS FOR ANALYSIS
NOTE 4: PHASE SEPARATION OCCURRING
NOTE 5: ANALYSIS NOT PERFORMED DUE TO EXCESSIVE FOAMING

LABORATORY SAMPLE NUMBER	1692-83G	1653-83G	1853-84G	574-84G	575-84G	576-84G	577-84G	1847-84G
REFERENCE			D7	CTOB3	CTOC2	HEADS	PITCH	D1
COMPOSITION	CTOE	CTOF	CTOP	DEPITCH DEWATER CTOB	DEPITCH CTOC			10% CTOP 90% WDSL
FLASH POINT (C)	204	106	174	236	212	XXXXXXXX	XXXXXXXX	60
POUR POINT (C)	3	15	-3	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	-33
WATER AND SEDIMENT (vol.%)	0.1	2	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
WATER (vol.%)	0.9	1.2	XXXXXXXX	1	3.5	XXXXXXXX	XXXXXXXX	XXXXXXXX
SULFUR (wt.%)	0.11	0.31	XXXXXXXX	0.11	0.14	0.15	0.39	XXXXXXXX
CORROSION	4c	4c	1b	3b	4a	XXXXXXXX	XXXXXXXX	1b
HEAT OF COMBUSTION (MJ/kg)	38.84	38.42	38.65	39	38.1	42.3	39.4	43.34
ASH (wt.%)	0.03	0.03	XXXXXXXX	0.001	0.002	XXXXXXXX	XXXXXXXX	XXXXXXXX
CARBON RESIDUE (wt.%)	0.78	0.7	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
VISCOSITY (cSt)								
@-20 C	XXXXXXXX	XXXXXXXX	NOTE 2	XXXXXXXX	XXXXXXXX	NOTE 3	NOTE 3	62.36
@ 0 C	XXXXXXXX	XXXXXXXX	NOTE 1	112.7	NOTE 2	NOTE 3	118.2	9.534
@20 C	1296	NOTE 3	XXXXXXXX	NOTE 1	30.9	18.46	12.37	4.749
@40 C	277.5	514.8	445.2	15.48	15.25	XXXXXXXX	XXXXXXXX	2.965
@70 C	53.13	73.78	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
@90 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
DISTILLATION RANGE (C)								
INITIAL B.P.	102.5	NOTE 5	XXXXXXXX	131	101	XXXXXXXX	XXXXXXXX	XXXXXXXX
10%	309	NOTE 5	XXXXXXXX	319	210.5	XXXXXXXX	XXXXXXXX	XXXXXXXX
50%	362	NOTE 5	XXXXXXXX	360.5	355.5	XXXXXXXX	XXXXXXXX	XXXXXXXX
90%	396	NOTE 5	XXXXXXXX	384.5	372.5	XXXXXXXX	XXXXXXXX	XXXXXXXX
END POINT	400	NOTE 5	XXXXXXXX	388.5	374.5	XXXXXXXX	XXXXXXXX	XXXXXXXX

NOTE 1: ROSIN ACIDS CRYSTALLIZING
NOTE 2: SAMPLE SOLID AT THIS TEMPERATURE
NOTE 3: SAMPLE TOO VISCOUS FOR ANALYSIS
NOTE 4: PHASE SEPARATION OCCURRING
NOTE 5: ANALYSIS NOT PERFORMED DUE TO EXCESSIVE FOAMING

LABORATORY SAMPLE NUMBER	2107-83G	1848-84G	1849-84G	2109-83G	2110-83G	1654-83G	1655-83G	1656-83G
REFERENCE		D2	D3					
COMPOSITION	25% CTOA 75% WDSL	25% CTOP 75% WDSL	40% CTOP 60% WDSL	50% CTOA 50% WDSL	50% CTOA 50% WDSL	50% CTOA 50% WDSL	50% CTOB 50% WDSL	50% CTOC 50% WDSL
FLASH POINT (C)	53	56	57	53	53	53	54	53
POUR POINT (C)	-42	-30	-39	-42	-39	-42	-42	-30
WATER AND SEDIMENT (vol.%)	1	XXXXXXXX	XXXXXXXX	2	0	1.8	1.1	0.6
WATER (vol.%)	0.05	XXXXXXXX	XXXXXXXX	0.2	0.4	0.2	0.15	0.6
SULFUR (wt.%)	0.19	XXXXXXXX	XXXXXXXX	0.12	0.11	0.21	0.14	0.17
CORROSION	4c	1b	3a	4c	4c	4c	4a	4c
HEAT OF COMBUSTION (MJ/kg)	43.46	43.13	42.53	41.96	41.97	42.2	42.29	41.84
ASH (wt.%)	0	XXXXXXXX	XXXXXXXX	0.01	0	0.02	0.03	0.05
CARBON RESIDUE (wt.%)	0.37	XXXXXXXX	XXXXXXXX	0.56	0.64	0.17	0.28	0.13
VISCOSITY (cSt)								
@-20 C	169.9	NOTE 1	NOTE 1	NOTE 3	NOTE 3	XXXXXXXX	XXXXXXXX	XXXXXXXX
@ 0 C	11.78	28.78	57.8	94.7	110.1	XXXXXXXX	XXXXXXXX	XXXXXXXX
@20 C	5.851	10.16	16.51	22.59	22.43	13.69	13.54	19.08
@40 C	3.673	5.572	8.353	11.04	10.94	7.357	7.29	8.867
@70 C	2.112	XXXXXXXX	XXXXXXXX	5.02	5.026	3.644	3.67	4.024
@90 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
DISTILLATION RANGE (C)								
INITIAL B.P.	155.5	XXXXXXXX	XXXXXXXX	89	99.5	116	134.5	100
10%	180	XXXXXXXX	XXXXXXXX	181	182	175.5	187.5	187.5
50%	236	XXXXXXXX	XXXXXXXX	279.5	191.5	249	263.5	266
90%	369	XXXXXXXX	XXXXXXXX	359	268	376	371	373
END POINT	375	XXXXXXXX	XXXXXXXX	361	370	377	376.5	375

NOTE 1: ROSIN ACIDS CRYSTALLIZING
NOTE 2: SAMPLE SOLID AT THIS TEMPERATURE
NOTE 3: SAMPLE TOO VISCOUS FOR ANALYSIS
NOTE 4: PHASE SEPARATION OCCURRING
NOTE 5: ANALYSIS NOT PERFORMED DUE TO EXCESSIVE FOAMING

LABORATORY SAMPLE NUMBER	2108-83G	1693-83G	1691-83G	568-84G	1850-84G	570-84G	1851-84G	2114-83G
REFERENCE				FUEL B4	D4	FUEL B6	D5	
COMPOSITION	50% CTOD 50% WDSL	50% CTOE 50% WDSL	50% CTOF 50% WDSL	50% CTOP 50% WDSL	50% CTOP 50%WDSL	50% CTOP (WASHED) 50% WDSL	60% CTOP 40%WDSL	75% CTOA 25% WDSL
FLASH POINT (C)	56	55	50	XXXXXXXX	59	XXXXXXXX	63	66
POUR POINT (C)	-39	-42	-42	XXXXXXXX	-36	XXXXXXXX	-24	-21
WATER AND SEDIMENT (vol.%)	0.1	0.9	0.7	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0
WATER (vol.%)	0.3	0.4	0.3	0.9	XXXXXXXX	0.4	XXXXXXXX	0.4
SULFUR (wt.%)	0.13	0.15	0.16	0.22	XXXXXXXX	0.18	XXXXXXXX	0.13
CORROSION	3a	4c	4c	4a	2c	4a	3a	4c
HEAT OF COMBUSTION (MJ/kg)	41.65	42.15	42.02	42	41.73	42	40.9	39.94
ASH (wt.%)	0.01	0.02	0	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0.01
CARBON RESIDUE (wt.%)	0.52	0.16	0.14	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0.74
VISCOSITY (cSt)								
@-20 C	NOTE 3	XXXXXXXX	XXXXXXXX	XXXXXXXX	NOTE 1	XXXXXXXX	NOTE 1	XXXXXXXX
@ 0 C	277.1	XXXXXXXX	XXXXXXXX	XXXXXXXX	174.2	XXXXXXXX	986.7	NOTE 4
@20 C	29.8	18.29	17.75	XXXXXXXX	30.44	XXXXXXXX	78.25	NOTE 4
@40 C	13	9.348	9.076	XXXXXXXX	13.38	XXXXXXXX	28.69	74.69
@70 C	5.592	4.322	4.001	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	19.51
@90 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
DISTILLATION RANGE (C)								
INITIAL B.P.	101.5	97.5	97.5	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	99.5
10%	180	186	288.5	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	194
50%	292.5	272.5	342.5	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	254.5
90%	381	365	366.5	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	390
END POINT	391	369	368.5	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	396

NOTE 1: ROSIN ACIDS CRYSTALLIZING

NOTE 2: SAMPLE SOLID AT THIS TEMPERATURE

NOTE 3: SAMPLE TOO VISCOUS FOR ANALYSIS

NOTE 4: PHASE SEPARATION OCCURRING

NOTE 5: ANALYSIS NOT PERFORMED DUE TO EXCESSIVE FOAMING

LABORATORY SAMPLE NUMBER	1852-84G	1854-84G	1855-84G	1856-84G	2111-83G	1857-84G		
REFERENCE	D6	D8	D9	D10		D11	E5	E6
COMPOSITION	75% CTOP 25% WDSL	10% CTOP 90% SDSL	25% CTOP 75% SDSL	40% CTOP 60% SDSL	50% CTOA 50% SDSL	50% CTOP 50% SDSL	10% DWTO 90% WDSL	25% DWTO 75% WDSL
FLASH POINT (C)	71	61	61	61	60	64	62	61.5
POUR POINT (C)	-3	-27	-33	-33	-24	-30	-30	-36
WATER AND SEDIMENT (vol.%)	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0	XXXXXXXX	XXXXXXXX	XXXXXXXX
WATER (vol.%)	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0.2	XXXXXXXX	XXXXXXXX	XXXXXXXX
SULFUR (wt.%)	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0.13	XXXXXXXX	XXXXXXXX	XXXXXXXX
CORROSION	3a	4a	1a	2c	4c	2c	1a	1a
HEAT OF COMBUSTION (MJ/kg)	39.99	44.54	43.66	42.53	41.77	41.88	44.32	43.3
ASH (wt.%)	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0.01	XXXXXXXX	XXXXXXXX	XXXXXXXX
CARBON RESIDUE (wt.%)	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0.55	XXXXXXXX	XXXXXXXX	XXXXXXXX
VISCOSITY (cSt)								
@-20 C	NOTE 2	48.07	NOTE 1	NOTE 1	NOTE 3	NOTE 1	29.66	370.1
@ 0 C	NOTE 1	8.422	18.19	65.26	195.5	240.7	8.365	17.69
@20 C	250.2	4.511	8.271	17.53	31.93	30.46	4.503	8.289
@40 C	74.04	2.838	4.727	8.855	14.77	14.02	2.856	4.765
@70 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	6.142	XXXXXXXX	XXXXXXXX	XXXXXXXX
@90 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
DISTILLATION RANGE (C)								
INITIAL B.P.	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	150.5	XXXXXXXX	XXXXXXXX	XXXXXXXX
10%	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	197	XXXXXXXX	XXXXXXXX	XXXXXXXX
50%	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	306.5	XXXXXXXX	XXXXXXXX	XXXXXXXX
90%	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	367	XXXXXXXX	XXXXXXXX	XXXXXXXX
END POINT	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	370	XXXXXXXX	XXXXXXXX	XXXXXXXX

NOTE 1: ROSIN ACIDS CRYSTALLIZING

NOTE 2: SAMPLE SOLID AT THIS TEMPERATURE

NOTE 3: SAMPLE TOO VISCOUS FOR ANALYSIS

NOTE 4: PHASE SEPARATION OCCURRING

NOTE 5: ANALYSIS NOT PERFORMED DUE TO EXCESSIVE FOAMING

LABORATORY SAMPLE NUMBER	2328-84G	2329-84G	2322-84G	2323-84G	2324-84G	2325-84G	567-84G	2112-83G
REFERENCE	E7	E8	E1	E2	E3	E4	FUEL B3	
COMPOSITION	40% DWTO 60% WDSL	50% DWTO 50% WDSL	10% DWTO 90% SDSL	25% DWTO 75% SDSL	40% DWTO 60% SDSL	50% DWTO 50% SDSL	50% DPTO 50% WDSL	50% DPTO (PPRIC) 50% WDSL
FLASH POINT (C)	62.5	62.5	63	64	65	66	57	57
POUR POINT (C)	-33	-33	-27	-30	-27	-24	-30	-36
WATER AND SEDIMENT (vol.%)	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	1	0
WATER (vol.%)	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	1.7	0.1
SULFUR (wt.%)	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0.18	0.16
CORROSION	1a	1a	1a	1a	1a	1a	4c	1b
HEAT OF COMBUSTION (MJ/kg)	42.42	41.84	44.29	42.89	42.56	41.89	41.7	41.6
ASH (wt.%)	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0.019	0
CARBON RESIDUE (wt.%)	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0.1	0.39
VISCOSITY (cSt)								
@-20 C	NOTE 1	NOTE 1	42.48	NOTE 1	NOTE 1	NOTE 1	XXXXXXXX	647
@ 0 C	51.51	130.7	8.196	17.58	48.7	136.4	162.2	79.88
@20 C	17.49	31.31	4.401	8.117	17.12	30.86	18.71	24.04
@40 C	8.848	14.16	2.811	4.731	8.74	14.09	9.178	12.38
@70 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	5.145
@90 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
DISTILLATION RANGE (C)								
INITIAL B.P.	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	107	160.5
10%	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	189.5	191
50%	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	290.5	301.5
90%	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	377.5	370
END POINT	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	377.5	375

NOTE 1: ROSIN ACIDS CRYSTALLIZING
NOTE 2: SAMPLE SOLID AT THIS TEMPERATURE
NOTE 3: SAMPLE TOO VISCOUS FOR ANALYSIS
NOTE 4: PHASE SEPARATION OCCURRING
NOTE 5: ANALYSIS NOT PERFORMED DUE TO EXCESSIVE FOAMING

LABORATORY SAMPLE NUMBER	566-84G	1858-84G	565-84G	2113-83G	572-84G	2330-84G	2331-84G	2332-84G
REFERENCE	FUEL B2	D12	FUEL B1		FUEL B8	E9	E10	E11
COMPOSITION	50% DPDW 50% WDSL	50% DPDW CTOB 50% WDSL	50% TOFA 50% WDSL	50% CTOE (ESTER) 50% WDSL	50% CTOP ESTER 50% WDSL	49.5% DW 49.5% SD 1% METH	49% DWTO 49% SDSL 2% METH	47.5% DW 47.5% SD 5% METH
FLASH POINT (C)	57	61	59	55	XXXXXXXX	40.5	35	19
POUR POINT (C)	-39	-36	-39	-33	XXXXXXXX	-24	-9	-6
WATER AND SEDIMENT (vol.%)	0.05	XXXXXXXX	0	1.4	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
WATER (vol.%)	0.05	XXXXXXXX	0.05	0.3	1.5	XXXXXXXX	XXXXXXXX	XXXXXXXX
SULFUR (wt.%)	0.15	XXXXXXXX	0.14	0.15	0.18	XXXXXXXX	XXXXXXXX	XXXXXXXX
CORROSION	1a	1b	1a	3b	4a	1a	1a	1a
HEAT OF COMBUSTION (MJ/kg)	41.2	41.58	42.2	41.94	41.9	41.64	41.34	40.86
ASH (wt.%)	0.001	XXXXXXXX	0	0.01	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
CARBON RESIDUE (wt.%)	0.13	XXXXXXXX	0.13	0.52	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
VISCOSITY (cSt)								
@-20 C	XXXXXXXX	NOTE 1	XXXXXXXX	NOTE 3	XXXXXXXX	NOTE 1	NOTE 2	NOTE 2
@ 0 C	70.74	87.78	19.59	34.28	121.9	144.9	109.8	62.21
@20 C	17.35	19.5	9.424	14.38	17.21	27.07	24.07	17.55
@40 C	8.877	9.796	5.525	7.265	8.156	12.45	11.98	8.75
@70 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	3.681	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
@90 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
DISTILLATION RANGE (C)								
INITIAL B.P.	162.5	XXXXXXXX	169.5	132.5	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
10%	191.5	XXXXXXXX	191	185.5	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
50%	310	XXXXXXXX	293.5	290.5	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
90%	378	XXXXXXXX	374	354.5	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
END POINT	380	XXXXXXXX	378	360	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX

NOTE 1: ROSIN ACIDS CRYSTALLIZING
NOTE 2: SAMPLE SOLID AT THIS TEMPERATURE
NOTE 3: SAMPLE TOO VISCOUS FOR ANALYSIS
NOTE 4: PHASE SEPARATION OCCURRING
NOTE 5: ANALYSIS NOT PERFORMED DUE TO EXCESSIVE FOAMING

LABORATORY SAMPLE NUMBER	2265-83G	569-84G	2333-84G	571-84G	573-84G	2269-83G	2266-84G	2267-83G
REFERENCE	FUEL #1	FUEL B5	E12	FUEL B7	FUEL B9	FUEL #5	FUEL #2	FUEL #3
COMPOSITION	47% CTOA 47% WDSL 6% METH	45% CTOP 45% WDSL 10% METH	45% DWTO 45% SDSL 10% METH	90% FUEL B6, 10% METH	45%CTOPE 45% WDSL 10% METH	50% CTOA 40% WDSL 10% METH	44% CTOA 44% WDSL 12% METH	44% CTOA 44% SDSL 12% METH
FLASH POINT (C)	28	XXXXXXXX	13	XXXXXXXX	XXXXXXXX	20	13	16
POUR POINT (C)	-21	XXXXXXXX	-27	XXXXXXXX	XXXXXXXX	-12	-33	-21
WATER AND SEDIMENT (vol.%)	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0.1	0.15
WATER (vol.%)	XXXXXXXX	11.2	XXXXXXXX	11.6	0.05	XXXXXXXX	0	0
SULFUR (wt.%)	XXXXXXXX	0.19	XXXXXXXX	0.17	0.17	XXXXXXXX	0.1	0.11
CORROSION	4a	4a	1a	4a	4a	4a	4a	4a
HEAT OF COMBUSTION (MJ/kg)	40.72	39.7	39.64	39.8	40.5	39.92	40.09	40.17
ASH (wt.%)	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0.02	0.02
CARBON RESIDUE (wt.%)	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	0.1	0.6
VISCOSITY (cSt)								
@-20 C	NOTE 3	XXXXXXXX	NOTE 1	XXXXXXXX	XXXXXXXX	NOTE 3	XXXXXXXX	XXXXXXXX
@ 0 C	142.2	XXXXXXXX	37.4	XXXXXXXX	78.57	216.8	XXXXXXXX	XXXXXXXX
@20 C	16.58	XXXXXXXX	12.09	XXXXXXXX	11.26	16.44	XXXXXXXX	XXXXXXXX
@40 C	XXXXXXXX	XXXXXXXX	6.365	XXXXXXXX	5.462	XXXXXXXX	XXXXXXXX	XXXXXXXX
@70 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
@90 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
DISTILLATION RANGE (C)								
INITIAL B.P.	66.5	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	65	66.5	65
10%	171.5	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	70	69.5	69.5
50%	272	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	284	264.5	294.5
90%	372.5	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	374.5	378	377
END POINT	373.5	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	378.5	382	381

NOTE 1: ROSIN ACIDS CRYSTALLIZING
NOTE 2: SAMPLE SOLID AT THIS TEMPERATURE
NOTE 3: SAMPLE TOO VISCOUS FOR ANALYSIS
NOTE 4: PHASE SEPARATION OCCURRING
NOTE 5: ANALYSIS NOT PERFORMED DUE TO EXCESSIVE FOAMING

LABORATORY SAMPLE NUMBER	2268-83G	2272-83G	2270-83G	2271-83G
REFERENCE	FUEL #4	FUEL #8	FUEL #6	FUEL #7
COMPOSITION	40% CTOA 40% WDSL 20% METH	50% CTOA 25% WDSL 25% METH	50% CTOA 50% METH	40% CTOA 40% WDSL 20% ETH
FLASH POINT (C)	14	11	12	17
POUR POINT (C)	-33	0	-9	-33
WATER AND SEDIMENT (vol.%)	0.15	XXXXXXXX	0.05	0.05
WATER (vol.%)	0	XXXXXXXX	0	0.05
SULFUR (wt.%)	0.07	XXXXXXXX	0.05	0.08
CORROSION	4a	4a	4a	4a
HEAT OF COMBUSTION (MJ/kg)	38.02	36.32	30.77	38.74
ASH (wt.%)	0.02	XXXXXXXX	0.02	0.01
CARBON RESIDUE (wt.%)	0.57	XXXXXXXX	0.55	0.59
VISCOSITY (cSt)				
@-20 C	NOTE 3	NOTE 3	NOTE 3	NOTE 3
@ 0 C	35.84	128.8	138	28.25
@20 C	6.686	11.22	7.132	8.987
@40 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
@70 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
@90 C	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
DISTILLATION RANGE (C)				
INITIAL B.P.	65	64	64	77
10%	68	67	65	78
50%	249	272	185.5	242
90%	374.5	370.5	373.5	379.5
END POINT	379.5	378.5	376.5	382.5

NOTE 1: ROSIN ACIDS CRYSTALLIZING
NOTE 2: SAMPLE SOLID AT THIS TEMPERATURE
NOTE 3: SAMPLE TOO VISCOUS FOR ANALYSIS
NOTE 4: PHASE SEPARATION OCCURRING
NOTE 5: ANALYSIS NOT PERFORMED DUE TO EXCESSIVE FOAMING

LABORATORY SAMPLE NUMBER	85-1603	85-1608	85-1604	85-1605	85-1606	85-1609	85-1607
REFERENCE	F6	F11	F7	F8	F9	F12	F10
COMPOSITION	100% TOFA-C4	100% TOFA-2	90% TO-4 10% SDSL	75% TO-4 25% SDSL	50% TO-4 50% SDSL	50% TO-2 50% SDSL	25% TO-4 75% SDSL
FLASH POINT (C)	250	240	78	74	62	61	58
POUR POINT (C)	-16	-30	-21	-30	-33	-33	-15
WATER AND SEDIMENT (vol.%)	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
WATER (vol.%)	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
SULFUR (wt.%)	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
CORROSION	1b	1b	1a	1a	1a	1a	1a
HEAT OF COMBUSTION (MJ/kg)	39.14	39	39.79	40.67	42.23	42.04	43.64
ASH (wt.%)	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
CARBON RESIDUE (wt.%)	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
VISCOSITY (cSt)							
@-20 C	NOTE 2	NOTE 2	NOTE 2	220.8	92.8	55.52	25.81
@ 0 C	109	83.68	78.02	48.05	21.83	20.24	10.48
@20 C	41.4	34.43	31.2	20.47	10.94	10.11	5.65
@40 C	20.08	17.45	15.6	10.94	6.13	5.96	3.57
@70 C	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
@90 C	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
DISTILLATION RANGE (C)							
INITIAL B.P.	174	236.5	189.5	180.5	172.5	162	167
10%	329	336	309	237.5	212.5	206.5	202.5
50%	344.5	343.5	347	340	313	304	269
90%	369.5	364.5	379.5	365.5	349.5	352.5	344
END POINT	369.5	366	381	366.5	352	355.5	350.5

NOTE 1: ROSIN ACIDS CRYSTALLIZING
NOTE 2: SAMPLE SOLID AT THIS TEMPERATURE
NOTE 3: SAMPLE TOO VISCOUS FOR ANALYSIS
NOTE 4: PHASE SEPARATION OCCURRING
NOTE 5: ANALYSIS NOT PERFORMED DUE TO EXCESSIVE FOAMING

APPENDIX III

ENGINE TEST RESULTS (DEWATERED TALL OIL)

A long term engine test was performed at the University of Saskatchewan to assess the effects of the dewatered tall oil fuel on engine performance and endurance.

Testing was performed on a Deutz model F2L 912 direct injection aircooled diesel engine.

The following report summarizes the results of this test.

Report and Test Results from Using
Dewatered Crude Tall Oil
blended with Diesel fuel in a
Deutz F2L 912 Aircooled Diesel Engine

Prepared for

Prince Albert Pulp Company Ltd.
Box 3001
Prince Albert, Saskatchewan S6V 5T5

by

W.B. Reed, P.Eng.
Department of Agricultural Engineering
University of Saskatchewan
Saskatoon, Saskatchewan S7N 0w0

June, 1985

Contents

Page

Introduction 1
Scope of Test 1
Results and Discussion 1
    Fuels 1
    Filtering 2
    Specific Fuel Consumption 2
    Maximum Engine Power 3
    General Engine Performance 3
    Engine Deposits 3
    Engine Wear 4
    Crankcase Oil Analysis 5
    Fuel Injection Pump and Injection Nozzles 5
Summary and Conclusions 5
Photographs - Figures 1-24 7-18
Appendix A - Engine Wear Measurements 19
Appendix B - Specific Fuel Consumption vs Engine Power 21-29
Appendix C - Engine Power vs Engine Speed 30-38
Appendix D - Wear Metal vs Engine Operating time 39-54

Introduction

This report is subsequent to the earlier reports of February, 1984 and January 1985 entitled "Report and Test Results from Using Crude Tall Oil Blends as a Fuel in a Diesel Engine." Following the time when the January 1985 report was issued the Deutz engine was rebuilt and reinstalled to drive the Froude dynamometer. The instrumentation and procedures for fuel preparation, fuel consumption and power measurement during the tests documented in this report were as for the previous report.

Scope of Test

The period of engine operation reported on within this report, include 100 engine hours with 100% Premium Diesel fuel during the engine break-in period, and 580 engine hours with 50/50:Dewatered CTO/Diesel fuel.

During the test period, 125 mL oil samples from the Deutz engine crankcase were taken every 20 hours for analysis of metal and other elemental content. The samples were analysed with a plasma-arc spectrometer at the Federated Co-operative Oil Refinery laboratory in Regina. The crankcase oil was drained and replaced with new oil every 60 hours of operation.

The Deutz engine was operated at a speed of 2000 rpm with a load of approximately 70% of maximum power. Fuel consumption and power output of the engine were measured.

Results and Discussion

Fuels

(a) Diesel Fuel: Co-op Red Premium Summer Grade Diesel Fuel was used during the engine break-in period of 100 hours. Co-op Red Premium Winter Grade P-30 Diesel Fuel was used or blended with the Dewatered Crude Tall Oil and used for 387 hours, after which the Summer Grade Diesel fuel was used for the remainder of the test.

(b) Dewatered Tall Oil: This fuel was derived from the Crude Tall Oil supplied by the Prince Albert Pulp Co. The dewatering was accomplished through the use of a thin film evaporator installed at the POS Pilot Plant in Saskatoon.

Fuel Preparation

The blended fuels consisted of mixing equal quantities of Diesel Fuel and dewatered CTO. The mixture was heated, using a hot water heating coil, in a 200 litre barrel until the fuel temperature was approximately 40°C.

The barrel full of fuel was allowed to stand for 24 hours or longer to allow lignin and crystals to settle to the bottom. A transfer pump with a floating intake hose and a series of filters were used to filter the fuel mixture before using in the engine. Approximately 20-25% of the fuel mixture (lower part of the barrel) was discarded since the solids contained in it rapidly plugged fuel filters.

Three filters were used in series for the filtering process. These were a Gresen 75 micron metal screen, a 30 micron Fram filter No. P1146 and a 10 micron Fram filter No. 1653.

Filtering

In addition to the pre-filtering procedure, the fuel was filtered during engine opertion. The primary fuel filter was a Fram PH8A (10 micron) and the final fuel fitler was a Fram P4102 (5-10 micron). A vacuum gauge installed at the outlet of the primary filter and a pressure gauge at the outlet of the final fuel filter indicated filter condition while the engine was operated.

Primary and secondary filter life was dependent on the procedure and effectiveness of the pre-filtering operation. Considerable variation in filter life occurred throughout the test. Filter life was greatly extended by maintaining a fuel temperature of about 25°C. The fuel was warmed by an electric heater located beneath the primary fuel filter.

Specific Fuel Consumption

The measurements of specific fuel consumption were made periodically and the fuel consumption at 18 kW is given in the table I below.

Table 1. Specific Fuel Consumption*

Engine Hours	Fuel	Engine Speed RPM	Power KW	SPFC g/kWh
103	Diesel(Winter)	2000	18	227
135	DCTO/Diesel(Winter)	2000	18	248
233	DCTO/Diesel(Winter)	2000	18	250
403	DCTO/Diesel(Winter)	2000	18	255
537	DCTO/Diesel(Winter)	2000	18	261
545	DCTO/Diesel(Winter)	2000	18	261
565	Diesel(Summer)	2000	18	242
647	DCTO/Diesel(Summer)	2000	18	248

*Note:
- Fuel injection timing 32°BTDC
- DCTO - Dewatered Crude Tall Oil
- SPFC vs Brake Power Curves are found in Appendix B.

The specific fuel consumption was lower with Diesel fuel than with

50/50:DCTO/Diesel fuel mixture. The SPFC with Diesel fuel ranged from 227-242 g/kWh at 18.0 kW power level and an engine speed of 2000 rpm. With the DCTO/Diesel mixture the SPFC ranged from 248-261 g/kWh at 18.0 kW power level and an engine speed of 2000 rpm. This difference amounts to 10 to 11% more fuel consumption when using the DCTO/Diesel mixture. The range of SPFC is due to changes in engine condition and in particular due to fuel injection nozzle condition.

The tables of maximum power and fuel consumption cannot always be directly compared from trial to trial because of changes in engine condition, particularly the condition of the fuel injector nozzles. The use of DCTO had an adverse effect on the fuel injector nozzles due to the carbon build-up on the nozzle tip. Partially clogged fuel injector nozzles appear to have a greater adverse effect on engine performance when burning DCTO blends than when burning Diesel fuel alone. This may be due to the higher viscosity of the DCTO blend which may result in a poor dispersion of the fuel from the nozzle. The maximum power output with various fuels is given in Table 2 and Appendix C.

General Engine Performance

The engine performance during this period of testing was little different from that reported in the previous report. The dewatered CTO blend was not noticeably different in terms of starting, exhaust gas temperature, exhaust smoke or general operation. Engine starting at temperatures near 0°C was better and quicker with Diesel fuel than with the tall oil blended fuels. Engine starting was prevented if the temperature was a few degrees lower than 0°C.

Table 2 Maximum Engine Power

Engine Hours	Fuel	Engine Speed r.p.m.	Max Power kW	SPFC g/kWh
104	Diesel(Winter)	2135	23.8	242
136	DCTO/Diesel(Winter)	2135	24.3	269
235	DCTO/Diesel(Winter)	2135	24.2	275
406	DCTO/Diesel(Winter)	2135	24.0	273
539	DCTO/Diesel(Winter)	2130	22.6	279
548	DCTO/Diesel(Winter)	2140	23.6	277
567	Diesel(Summer)	2135	24.6	249
649	DCTO/Diesel(Summer)	2140	23.6	276

Note: - Fuel injection timing was 32° BTDC
- DCTO - Dewatered Crude Tall Oil
- Brake Power vs Engine Speed Curves are found in Appendix C.

Engine Deposits

Cylinder Head and Valves: The engine was operated for a total of 680 hours (100 hours with 100% Diesel and 580 hours with 50/50:Diesel/DCTO) without dismantling the engine except for removal of the fuel injector nozzles after 100 and after 541 engine hours. The deposits on the cylinder heads may be seen in the photographs of Figures 1 to 6. There was not a large amount of deposit on the cylinder head or the top valve faces, but a considerable quantity of soft oily carbon had built up on the intake valve head and stem. The intake valve port had some soft carbon accumulation. The accumulation is believed due to crankcase oil passing between the valve stem and guide.

Cylinders and Pistons: The photographs of Figures 7 to 12 show the deposits on the piston tops, on the piston and within the cylinders. Although the deposits were not excessive on the piston tops, there was a significant amount of hard carbon on the cylinder wall above the rings. The deposits had caused some interference, at the top of each piston, with the cylinder wall and resulted in some visible wear of the piston surface.

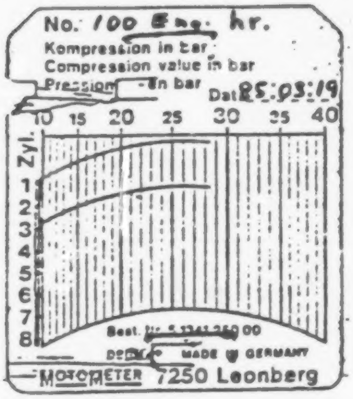
Engine Wear

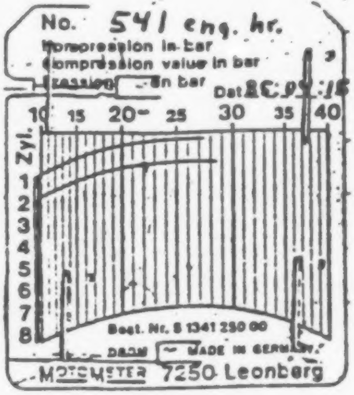
The dimensions of the engine parts after 680 hours are given in Appendix A, and indicate the amount of wear.

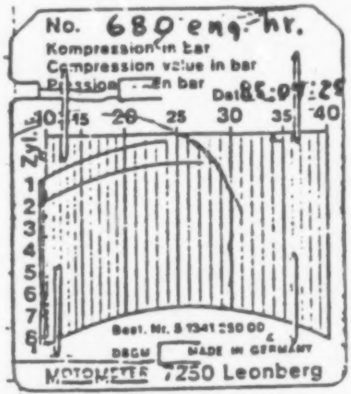
Cylinder and Pistons: The wear on No. 1 cylinder was .053 mm and on No. 2 cylinder was .046 mm. These amounts are well below the wear limit of 0.201 mm. The wear on the piston rings was small, as was the piston wrist pin clearance (Fig. 13 and 14).

Cylinder Head and Valves: There was wear on the valve stems, with the exhaust valve nearing the limit value for wear. Valve guide wear was also nearing the limit value.

The exhaust valve face and seat in No. 1 cylinder head was in poor condition with evidence of leakage. This is confirmed by the lower compression reading on that cylinder at the end of the test. The compression readings at 100, 541 and 680 hours are shown below.







Crankshaft and Bearings: The crankshaft journals and bearings were in good condition. The clearances were within the nominal clearances. The condition of these parts can be seen in Figures 15 to 20.

Camshaft: The camshaft journals and bearings were in good condition. The cam lobes were worn, with No. 3 lob having .043 mm of wear. The surface condition of the journals and lobes was polished and normal in appearance as seen in Figure 21.

The camshaft followers were pitted, as in previous trials, and would lead to eventual camshaft failure. Figure 22.

Oil Pump: The oil pump was in good condition. The outlet port showed no evidence of wear as compared to the pumps in previous trials. Figure 23.

Diesel Fuel Pump and Injector Nozzles: The calibration of the fuel injector pump showed that fuel delivery was within specifications. A pump speed of 900 rpm delivered 54 and 58 mL of fuel to No. 1 and No. 2 cylinders respectively per 1000 revolutions of the pump. The pump plungers and barrels were removed and retained for wear analysis.

The injector nozzles required servicing after 441 hours of engine operation, due to carbon buildup and blockage of one of the nozzle tip ports. The failure was noted by an increase in exhaust gas temperature of about 40°C and a noticeable drop in maximum engine power and an increase in fuel consumption. Shown in Fig 24 are the nozzles when removed at the end of the test.

Crankcase Oil Analysis

The Lubriscan crankcase oil analysis results are graphically presented in Appendix D. Throughout the test the levels of iron, aluminum, copper, lead, tin and chromium were below the acceptable limit values.

Some of the other element levels were variable. Near the end of the test the level of sodium in the oil increased quite rapidly. The zinc and magnesium content was high and variable. Sulfur, phosphorous and calcium were also variable. There is no explanation for the variability of the level of these elements.

The viscosity of the oil samples was quite uniform throughout the test, but increased after or during the oil change period. The viscosity though remained in the value for a SAE 30 oil.

Summary and Conclusions

Dewatered crude tall oil blended with Diesel fuel in a ratio of 1 to 1 performed well in the Deutz F2L912 aircooled engine with regard to general engine performance. Engine starting at ambient air temperature below 5°C was more difficult than with Diesel fuel alone. Temperatures slightly below 0°C made starting difficult or impossible.

Fuel consumption measurements indicated that 10-11% more of the blended fuel was used than 100% Diesel fuel. The maximum power output of the engine was very little different with the dewatered crude tall oil than with the Diesel fuel.

Fuel filter life was short but was greatly extended by maintaining the blended fuel at a temperature of about 25°C. Filter problems were related to the techniques of blending and decanting the fuel after the tempo treating process. Low ambient temperatures increased filtering problems since the fuel could not be maintained at 25°C.

The fuel injection pump performed without difficulty during the test and was delivering the specified volume of fuel at the end of the tests. The tips of the fuel injector nozzles accumulated hard carbon deposits which eventually plugged one of the nozzle ports; the blended fuel being the apparent cause of the short life.

The condition of the journals and bearings of crankshaft and camshaft were good at the end of the test, although the lobes of the camshaft were worn and cam followers were pitted. This would eventually result in camshaft failure.

Cylinder, piston and ring wear was not excessive, but hard carbon deposits had built up on the piston surfaces above the rings. These deposits had not caused serious problems although it may be contributed to the poor condition of one exhaust valve. The valve was apparently leaking as indicated by the lower compression reading. the deposits could also be expected to eventually result in piston and cylinder wear.

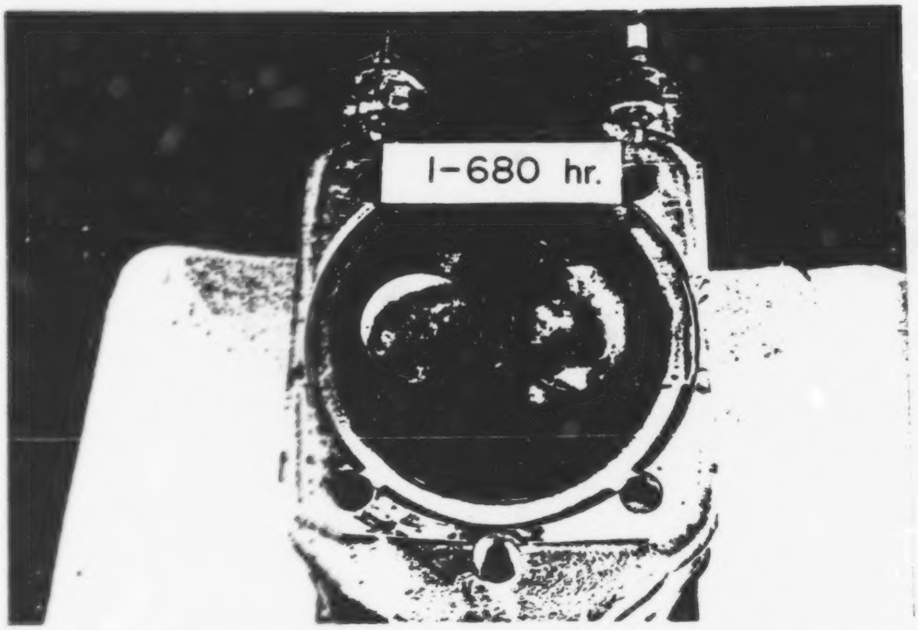


Fig. 1. No. 1 Cylinder head with valves.

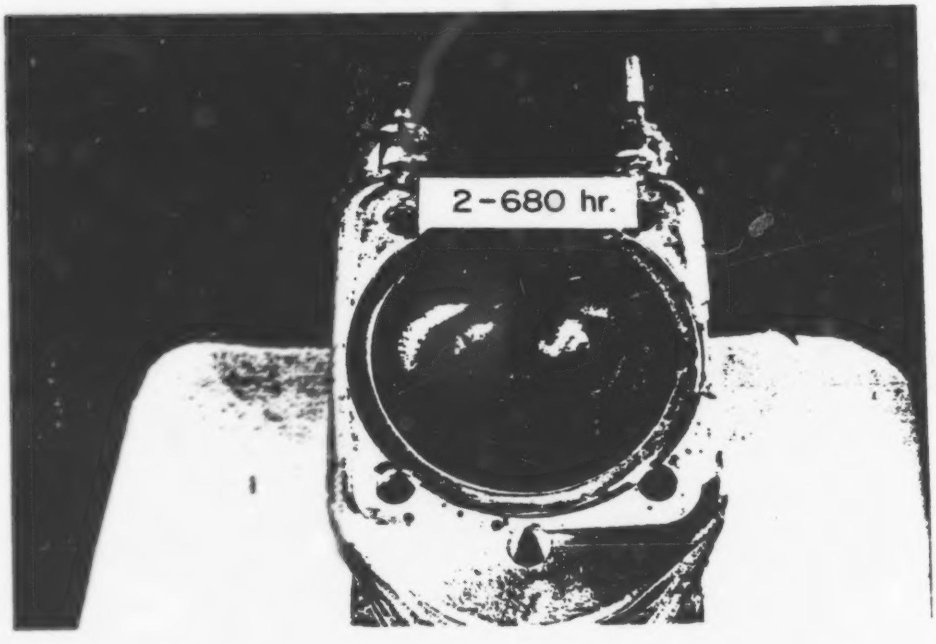


Fig. 2. No. 2 Cylinder head with valves.

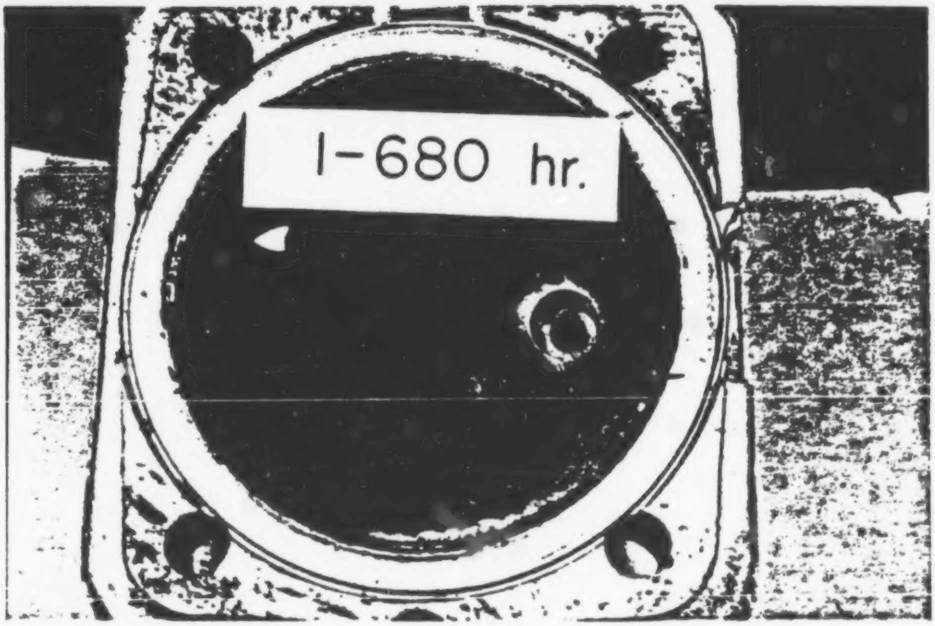


Fig. 3. No. 1 Cylinder head with valve removed.

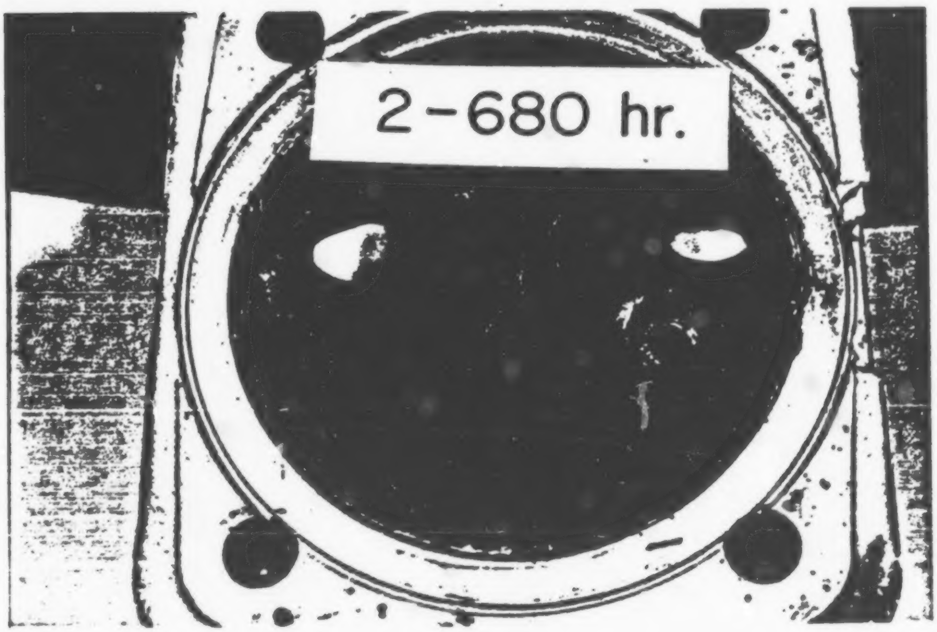


Fig. 4. No. 2 Cylinder head with valves removed.

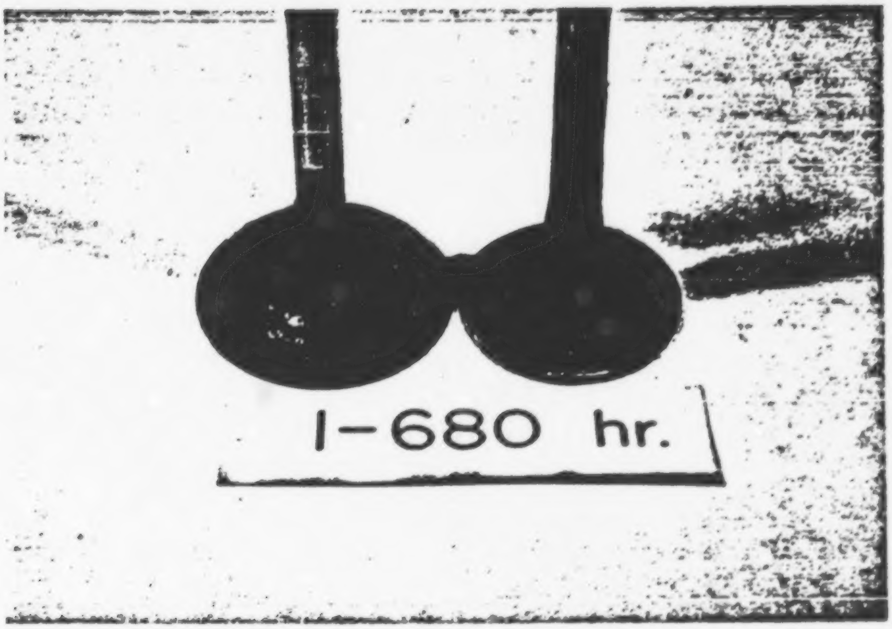


Fig. 5. Valves from No. 1 Cylinder head

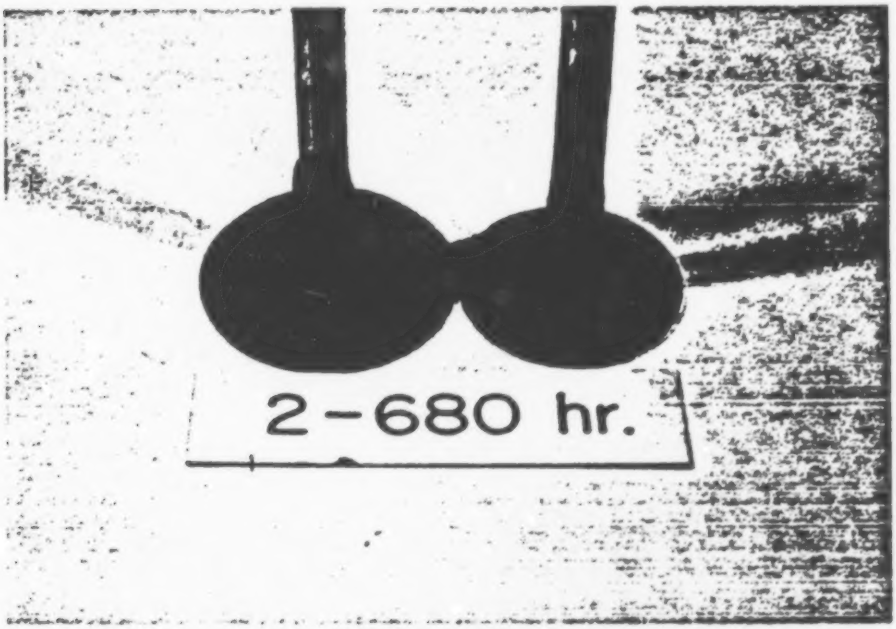


Fig. 6. Valve from No. 2 Cylinder head.

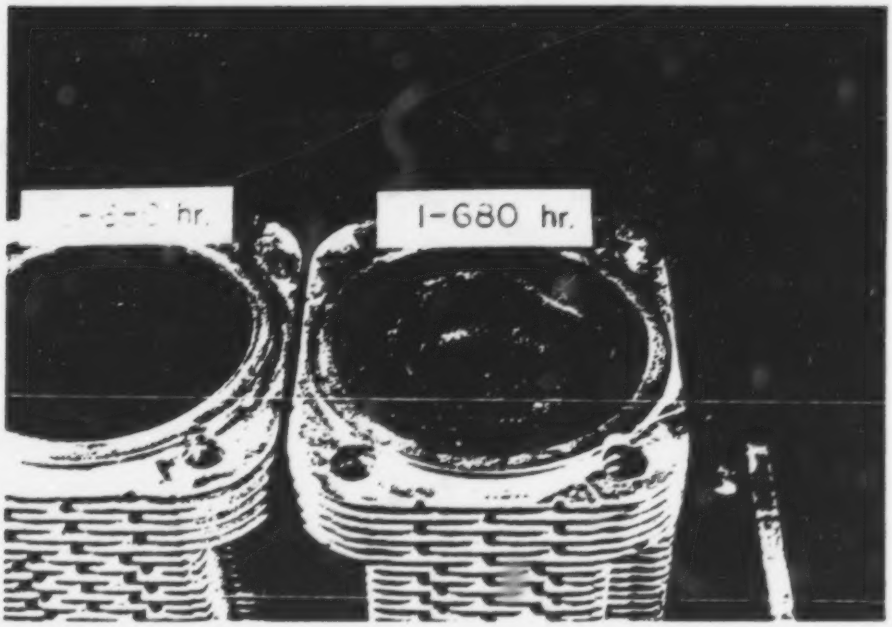


Fig. 7. Top of No. 1 Piston.

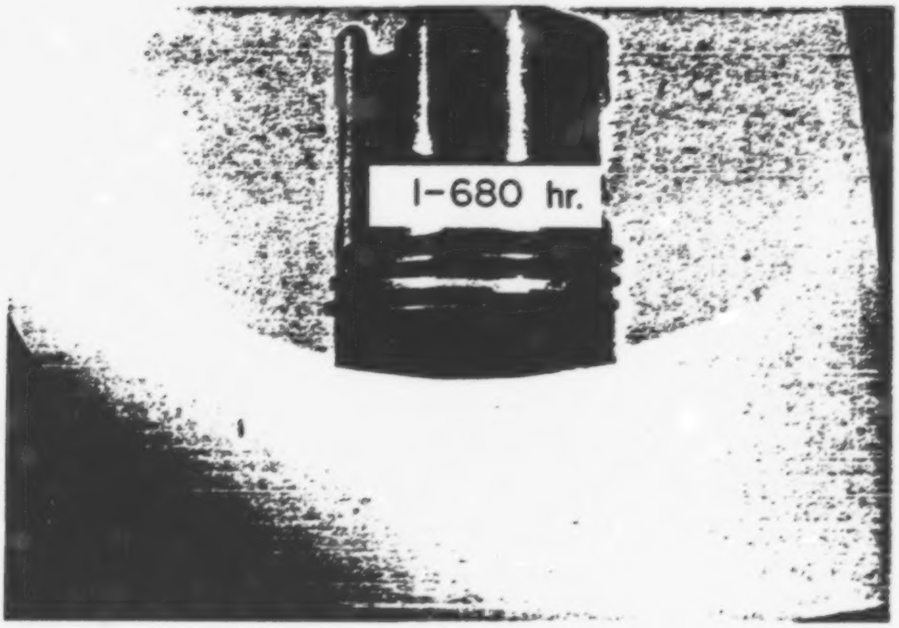


Fig. 8. No. 1 Piston

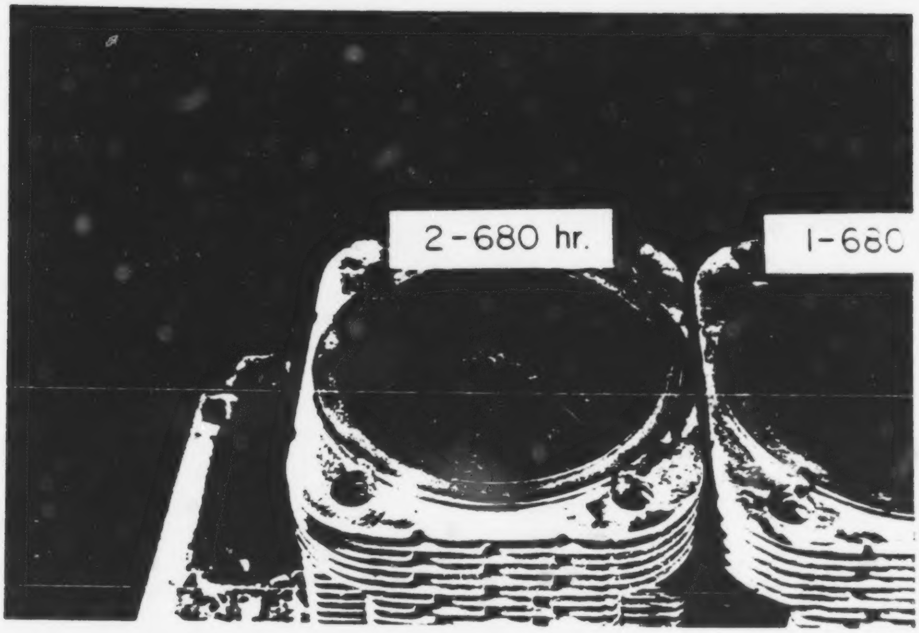

2-680 hr.
1-680

Fig. 9. Top of No. 2 Piston.

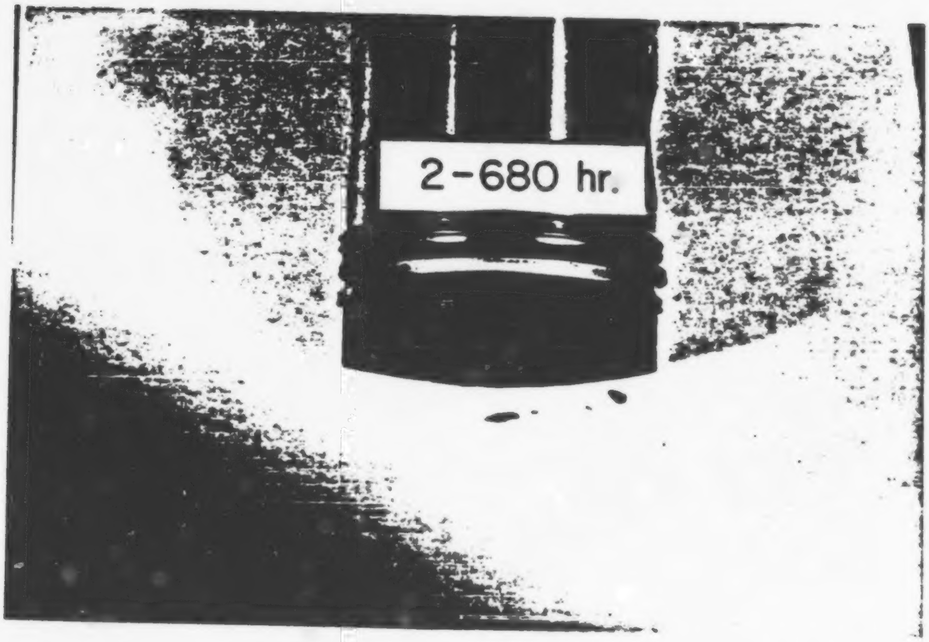


Fig. 10. No. 2. Piston.

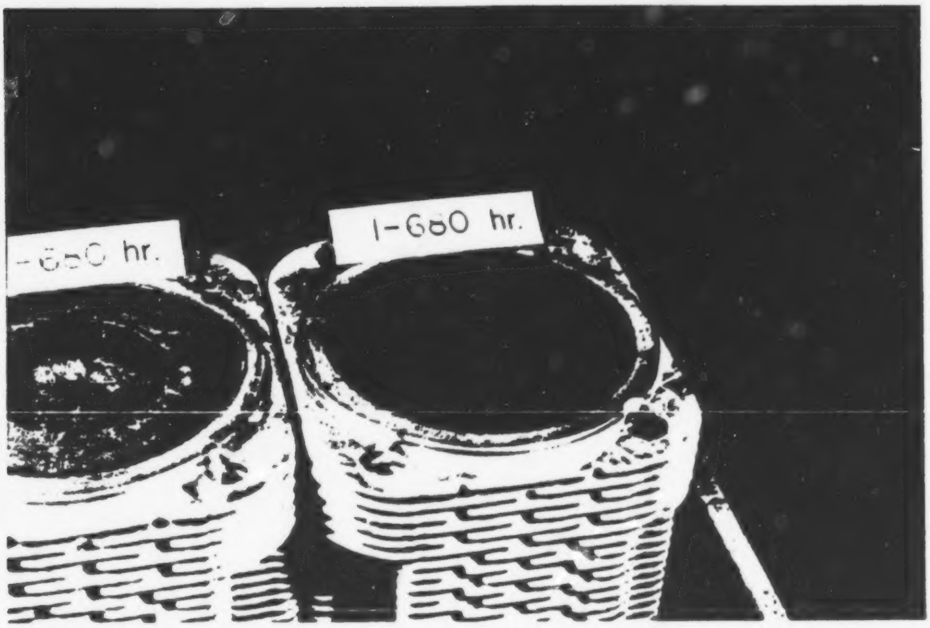

-680 hr.
1-680 hr.

Fig. 11. Interior view of No. 1 Cylinder.

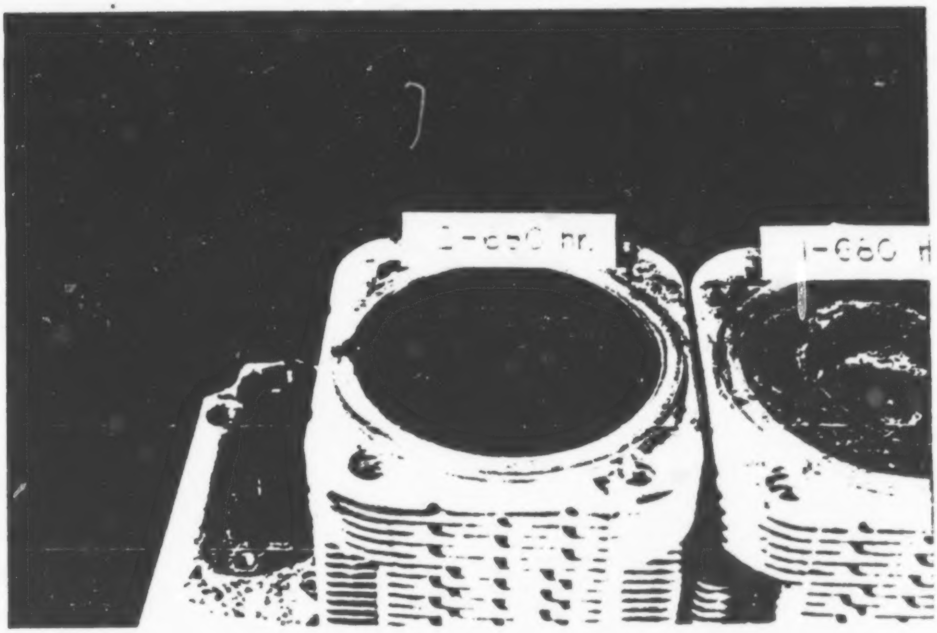

2-680 hr.
1-680 h

Fig. 12. Interior view of No. 2 Cylinder.

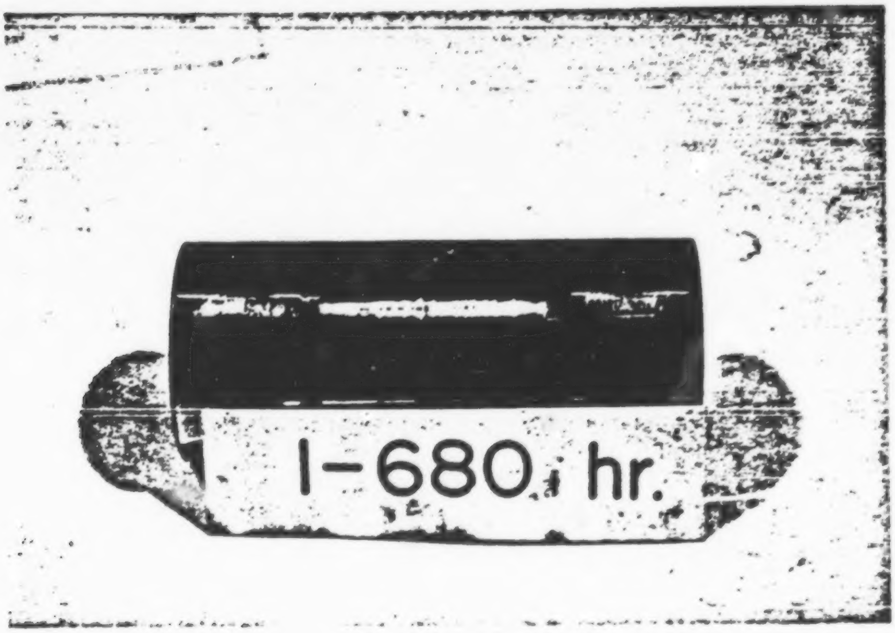


Fig. 13. Piston pin from No. 1 Piston

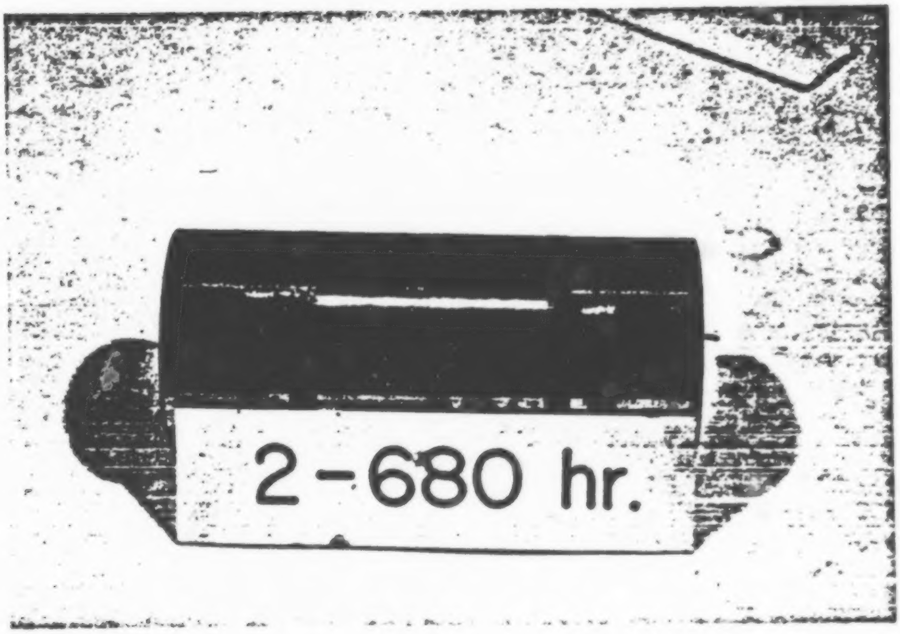


Fig. 14. Piston pin from No. 2 Piston

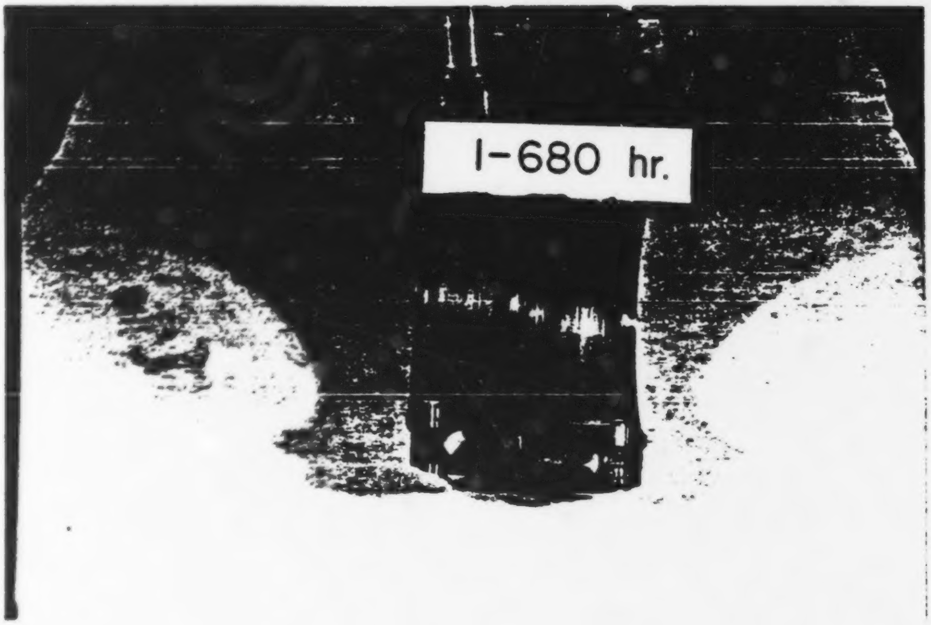


Fig. 15. Bearings from No. 1 Connecting Rod.

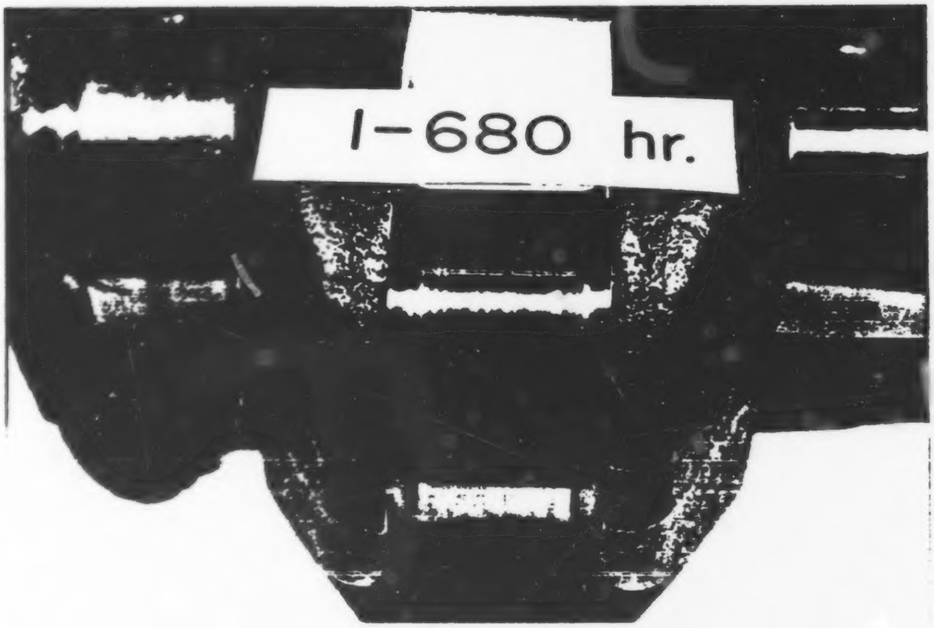


Fig. 16. Crankshaft Journal for No. 1 Connecting Rod.

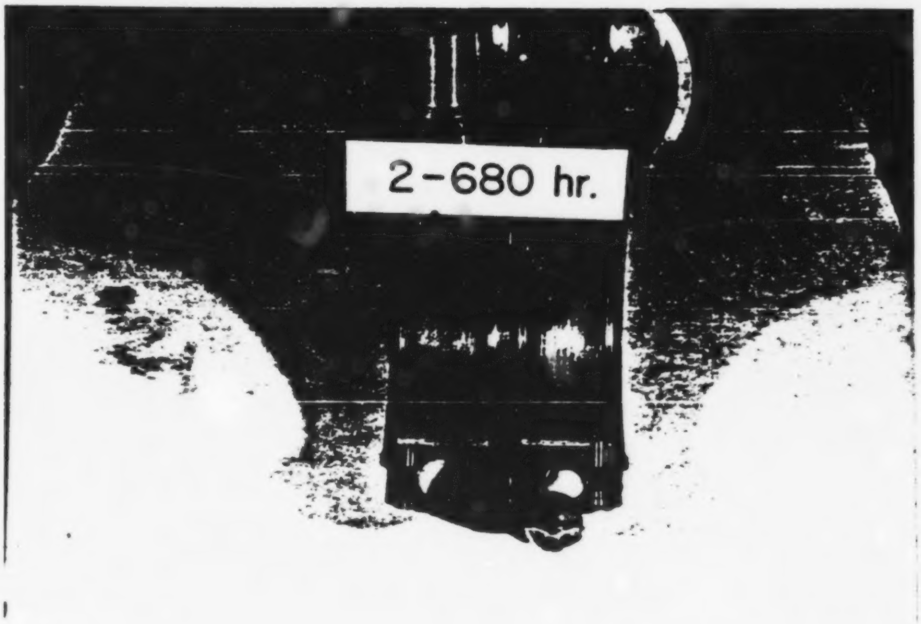


Fig. 17. Bearings from No. 2 Connecting Rod.

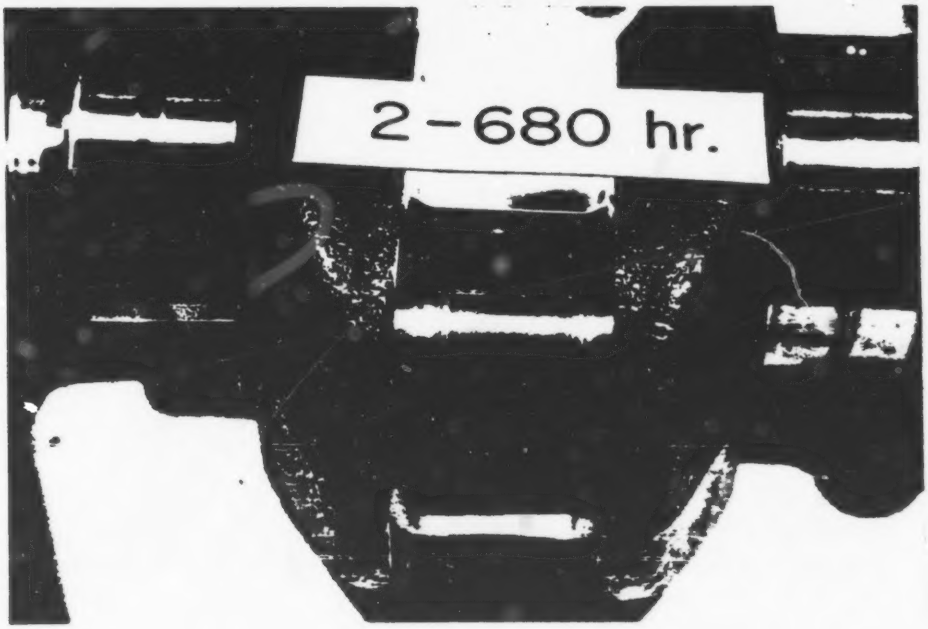


Fig. 18. Crankshaft Journal for No. 2 Connecting Rod.

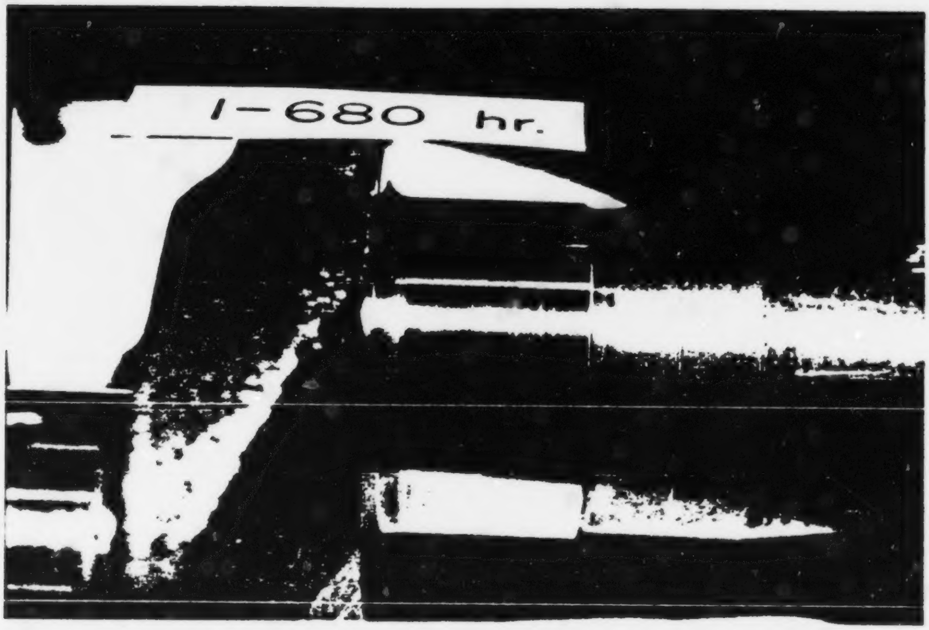


Fig. 19 Rear Journal of Crankshaft.

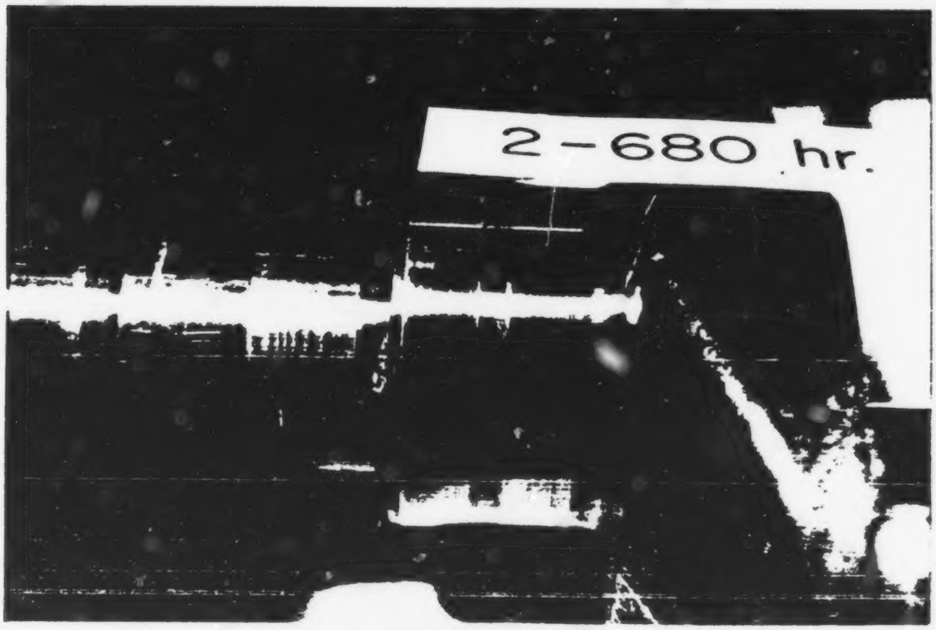


Fig. 20. Front Journal of Crankshaft.

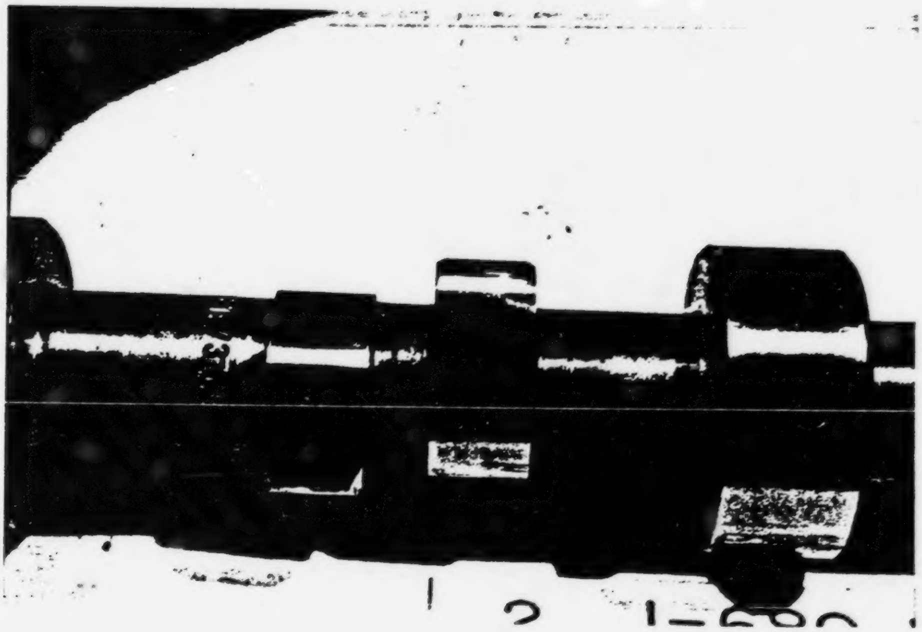


Fig. 21. Camshaft lobes and journals.

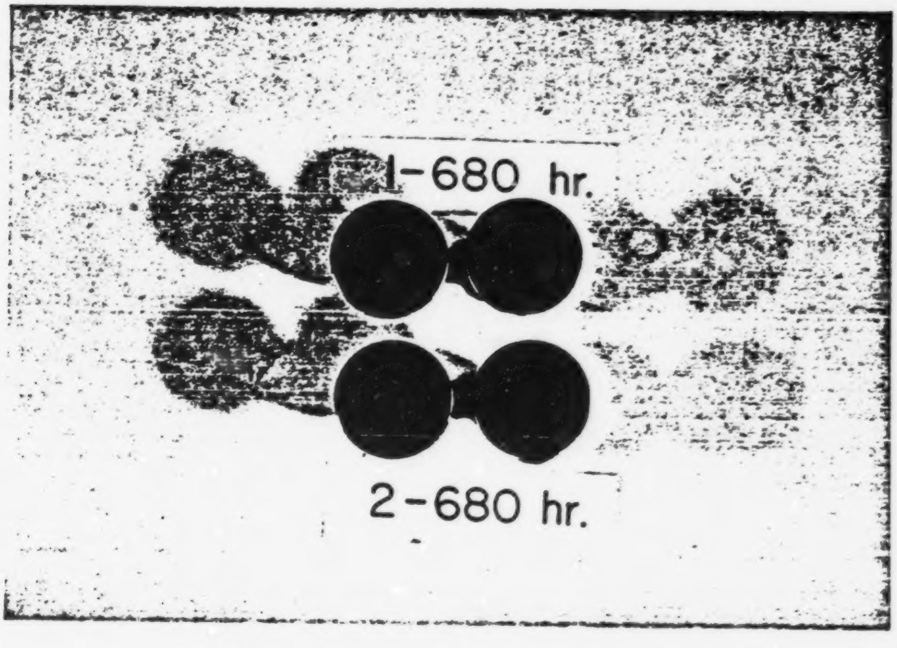

1-680 hr.
2-680 hr.

Fig. 22. Camshaft followers.

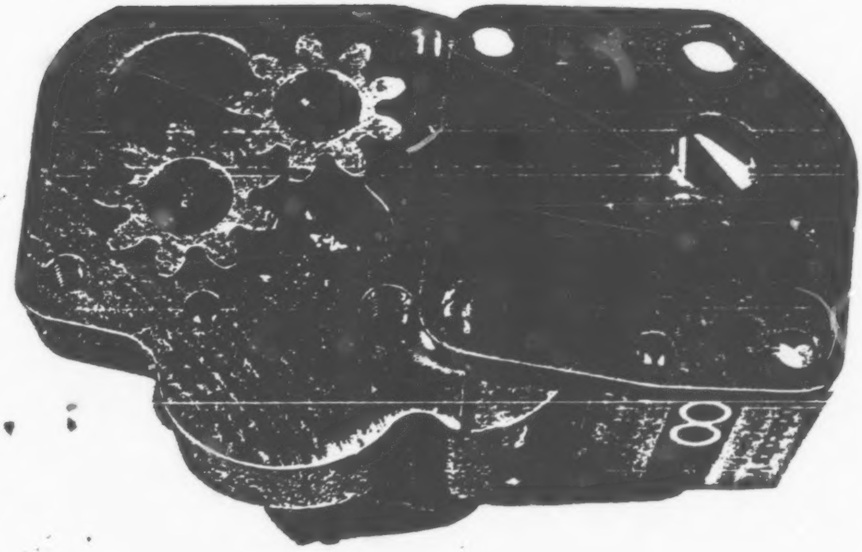


Fig. 23. Engine Oil Pump.

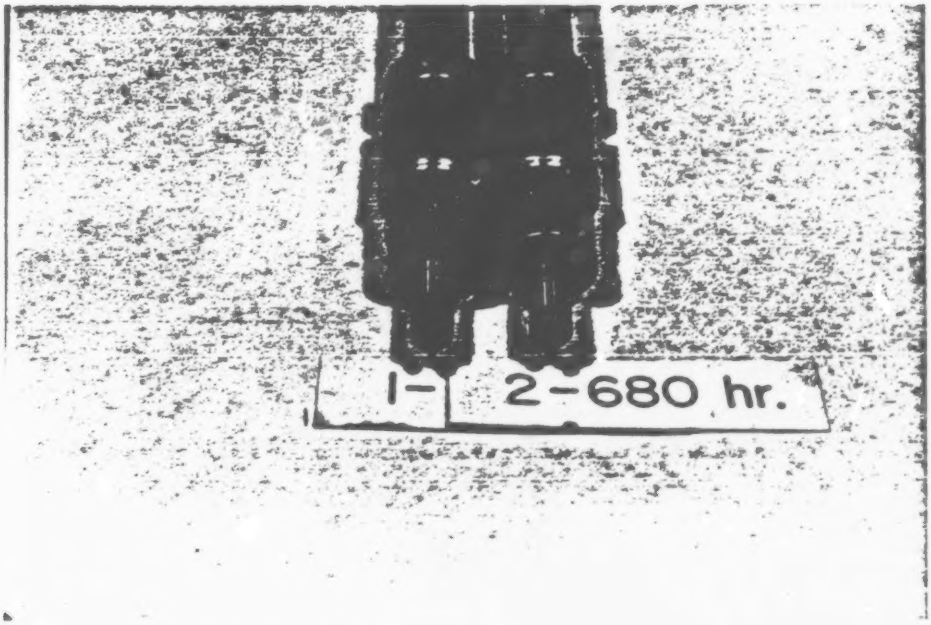


Fig. 24. Fuel injector nozzles.

Note: The fuel injector nozzles were mreoved and serviced at 411 engine hours. The above nozzles had operated 240 hours with 50/50:Diesel/LCTO.

Appendix A

Deutz - F2L912 - May, 1985

Summary of Engine Wear Measurements - 680 Engine Hours
All listed parts replaced at 0 hours.
- Measurements in mm Unless Otherwise Noted

1. Piston rings

	End Gap	Max Allowable	Side Clearance	Max All
Cylinder #1				
Top ring	0.71	4.0	0.10	0.5
Middle ring	0.74	4.0	0.08	0.5
Oil ring	0.51	2.5	0.05	0.15
Cylinder #2				
Top ring	0.76	4.0	0.10	0.5
Middle ring	0.74	4.0	0.10	0.5
Oil ring	0.51	2.5	0.05	0.15

2. Cylinder liners - Nominal Diameter 3.937 + 0.0008

	Diameter	Out of Round	Taper	Wear	Wear Limit
#1	100.020	.013	.010	.053	.201
#2	100.050	0.	.013	.046	.201

3. a)Valve Guides and Stems

	Stem Diam.	Limit	Guide Bore	Limit	Clearance
#1 Intake	7.915	7.945	7.988-8.006	8.016	.091
Exhaust	7.902	7.920	7.986-7.998	8.016	.097
#2					
Intake	7.915	7.945	7.983-7.988	8.016	.071
Exhaust	7.902	7.920	7.981-7.998	8.016	.097

Nominal Stem Diameter - Intake - 7.960-.015
Exhaust - 7.940-.015
8.000+.015
Guide Bores
Allowable Clearances
Intake - 0.041-.071
Exhaust - .061-.015

b) Valve Springs
Nominal Length - 60.000+1.900
Limit - 56.000
All Springs 58.738

4. Crankshaft Nominal Journal Diameter 62.000-(.010- .028)
Front Journal - 61.976 (main)
Rear Journal - 61.976 (main)

Nominal Bearing Bore (I.D.) - 62.050 + .041
Front Bearing Bore - 62.073
Rear Bearing Bore - 62.070

Nominal Crank Pin Journal Diameter 59.959 + .041
#1 Cylinder - 59.952
#2 Cylinder - 59.954

Nominal Journal to Bearing Clearance .041 - .099
#1 Cylinder .094
#2 Cylinder .094

No measureable out of round on any crankshaft journals.
Centre Journal Nominal Diameter 70.000-.028
Measured 69.982

5. Camshaft
No measurable out of round on any of the journals.
Nominal lift - 8.000
Limit value = N/A

Cam# (rear to front)	Lift
1	7.917
2	7.917
3	7.907
4	7.943

	Bearing bore	Journal diameter	Clearance
Front	51.989	51.930	.058
Middle	52.009	51.930	.079
Rear	47.955	47.943	.013

6. Wrist Pins
Nominal Diameter of Pins - 35.000 - .005
Nominal bore of Bearings - 35.039 + .046

Nominal Clearance - .041 - .091
Clearance Limit - .249

	Pin diam.	Bearing Bore	Clearance
#1	34.999	35.090	.091
#2	34.999	35.075	.076

Appendix B

Specific Fuel Consumption Versus Engine Power

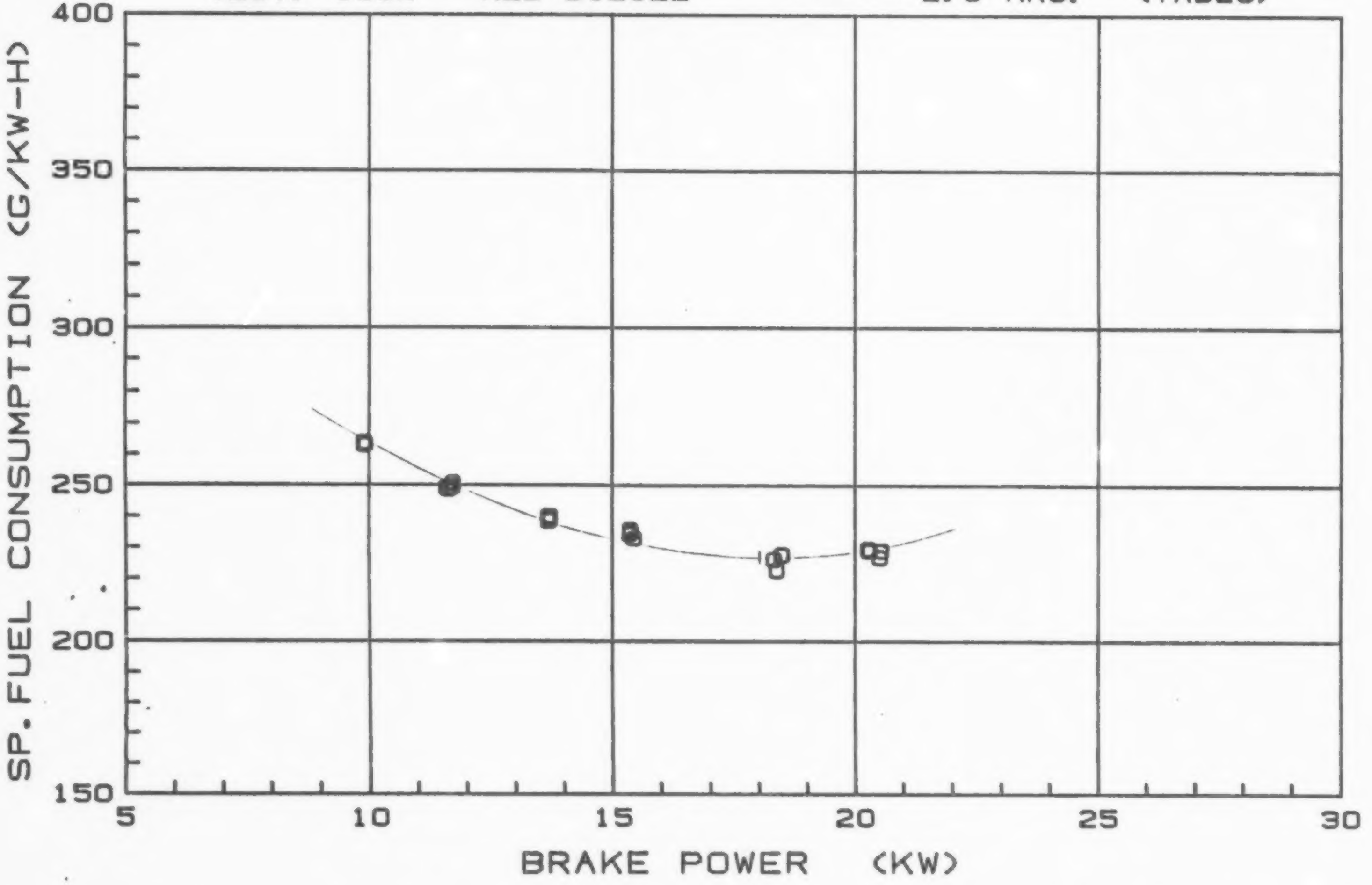
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAR. 20, 1985 -ENGINE: DEUTZ F2L912 2 CYL.

TEST: 100% RED DIESEL ------2.8 HRS. (TAD20)



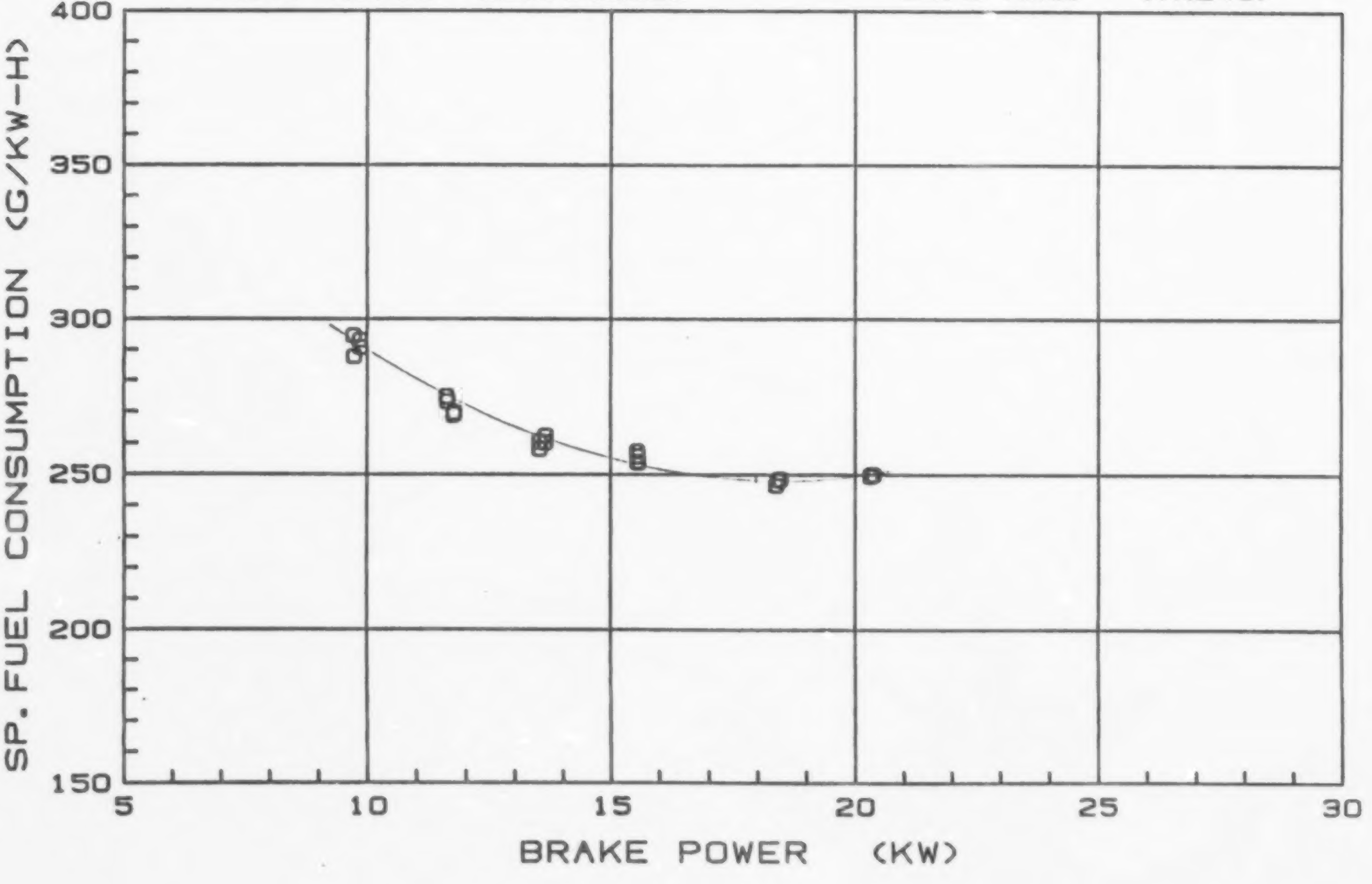
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAR. 22, 1985 -ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50/50 DEW/DIESEL -----34.6 HRS. (TAL49)



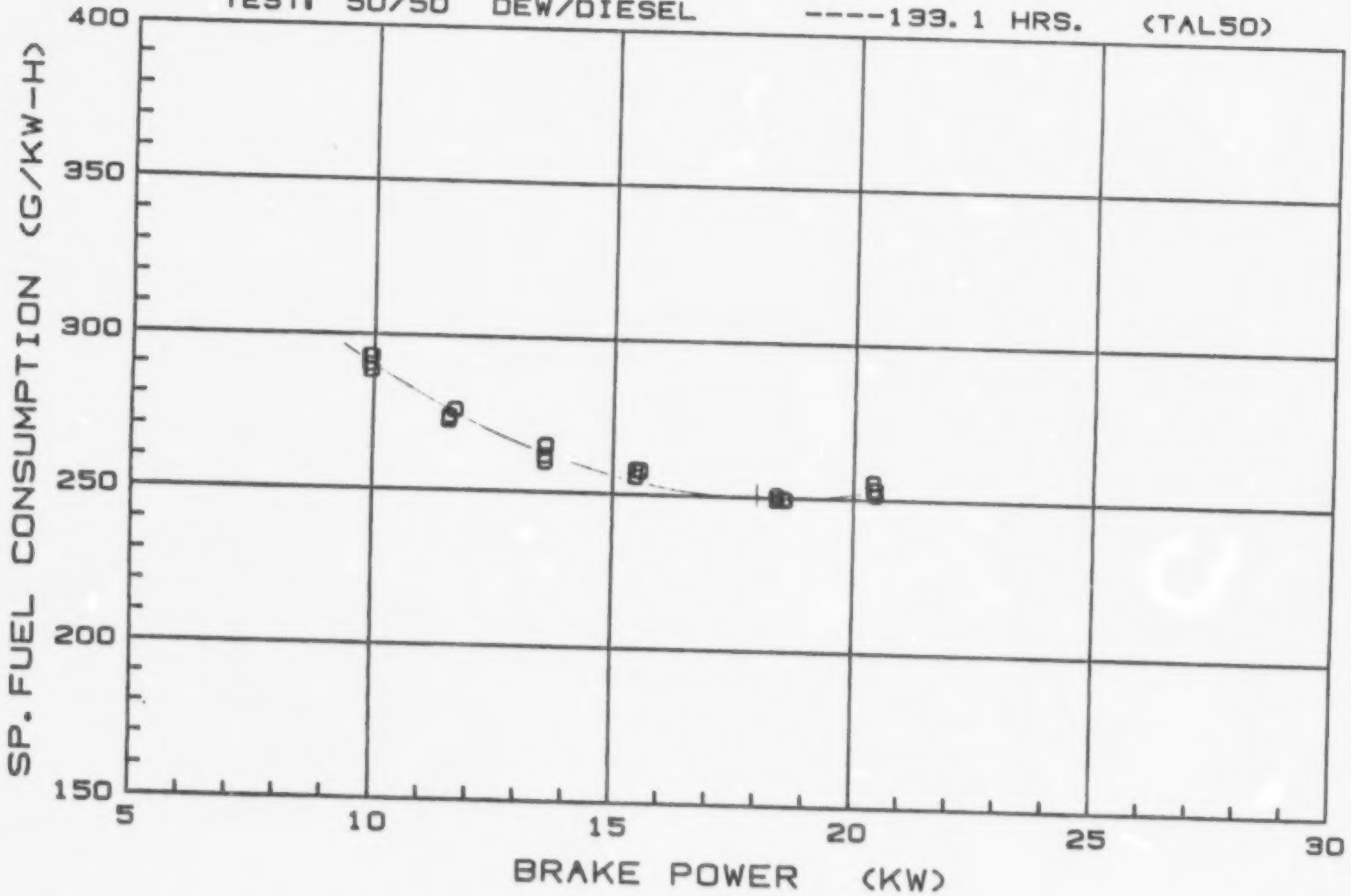
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

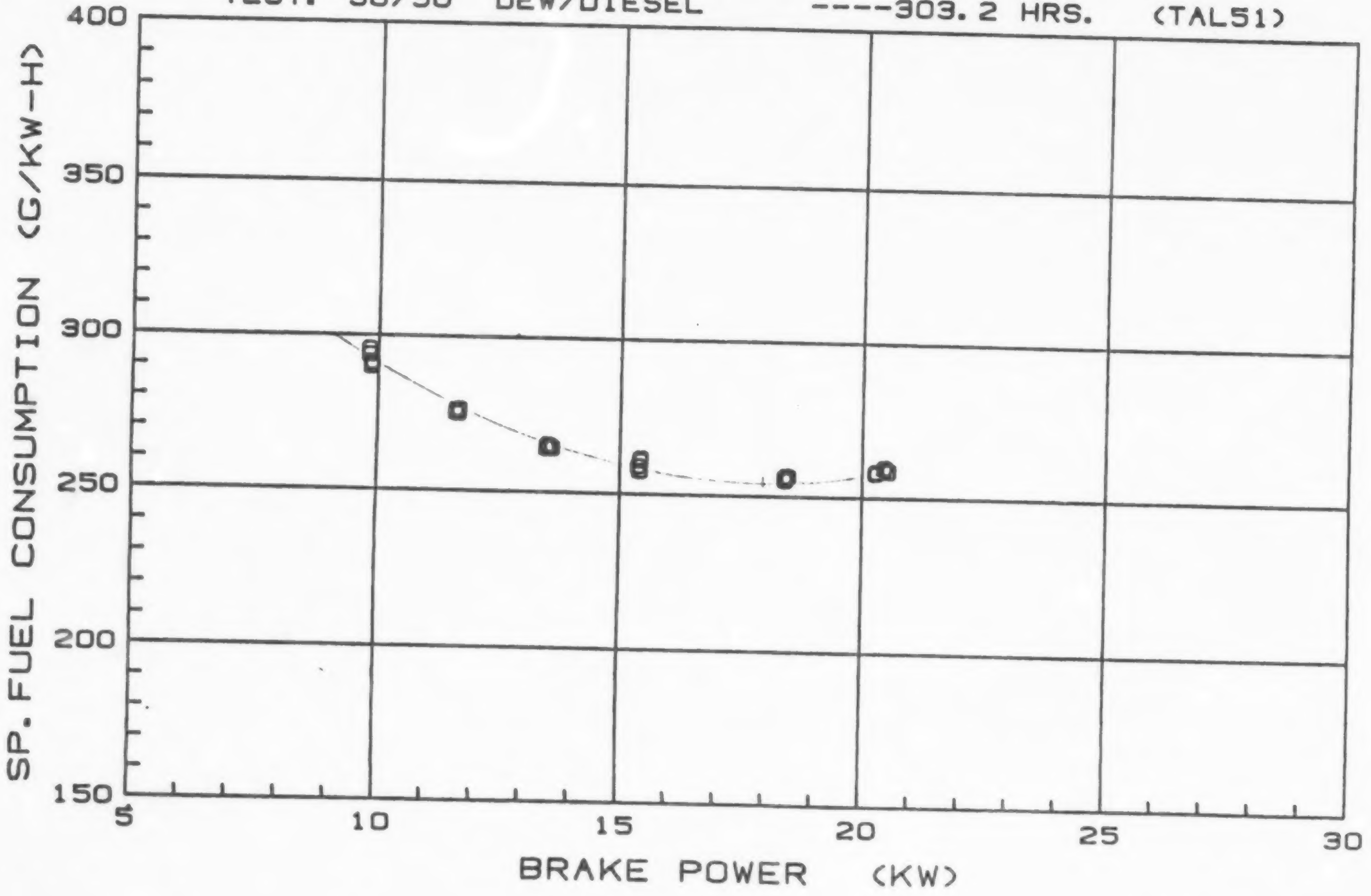
DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAR. 28, 1985 -ENGINE: DEUTZ.F2L912 2 CYL.

TEST: 50/50 DEW/DIESEL ----133.1 HRS. (TAL50)



UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL
PRINCE ALBERT PULP COMPANY LTD.
DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*
DATE: APR. 08, 1985 -ENGINE: DEUTZ F2L912 2 CYL.
TEST: 50/50 DEW/DIESEL ----303.2 HRS. (TAL51)



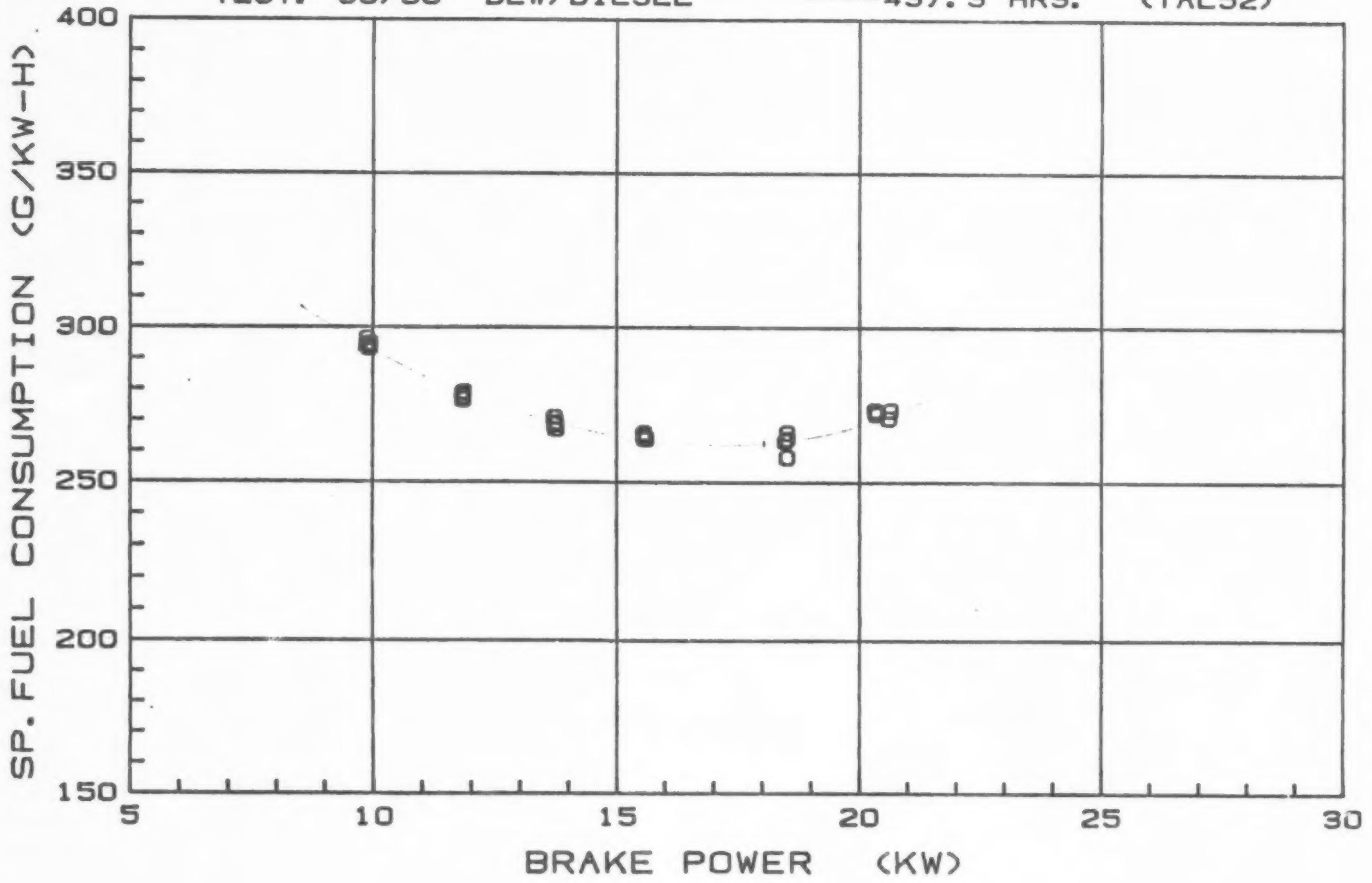
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: APR. 14, 1985 -ENGINE: DEUTZ·F2L912 2 CYL.

TEST: 50/50 DEW/DIESEL ----437.3 HRS. (TAL52)



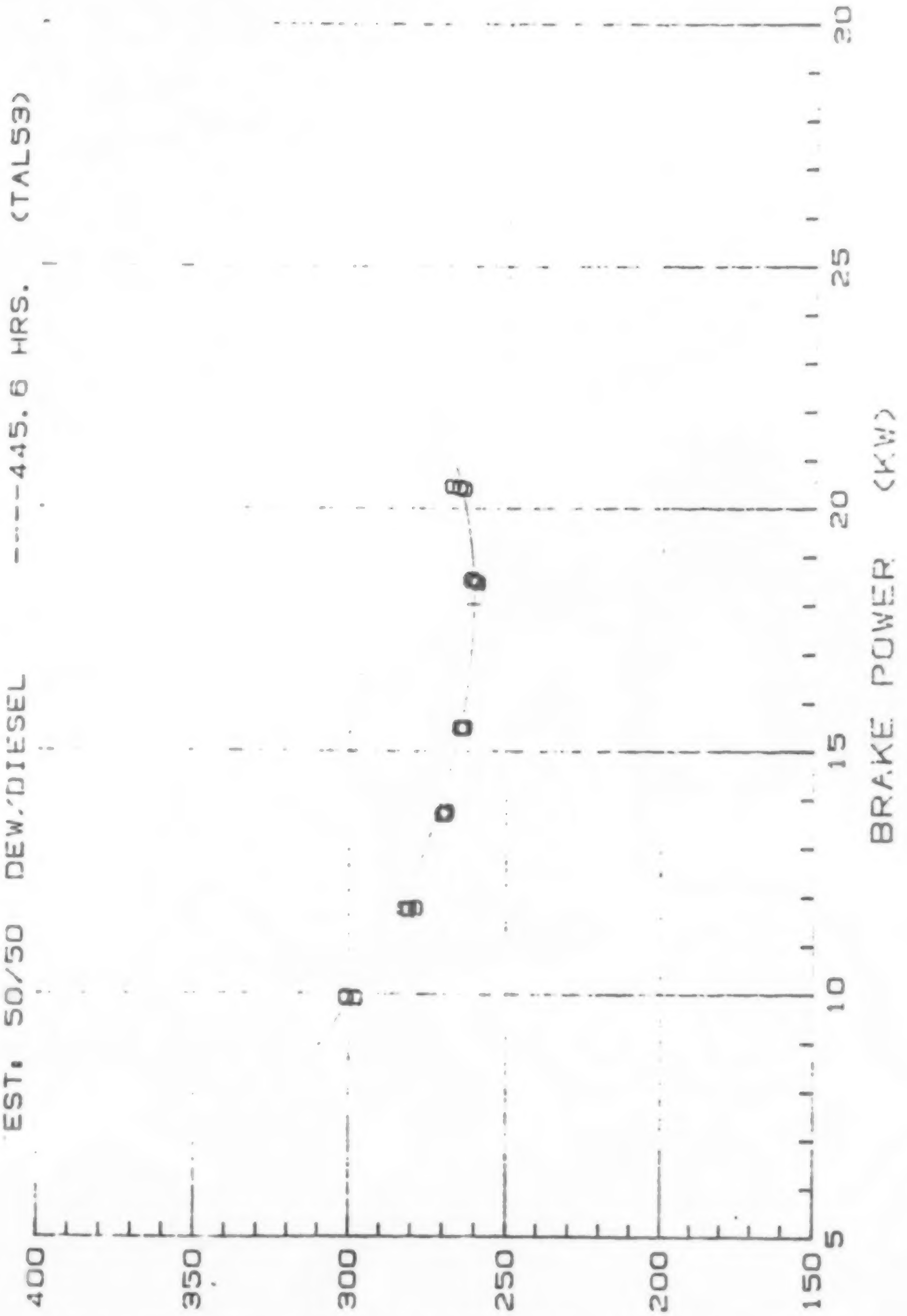
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERO*

DATE. APR. 16.1985 -ENGINE. DEUTZ F2L912 2 CYL.

EST. 50/50 DEW/DIESEL ----445.6 HRS. (TAL53)



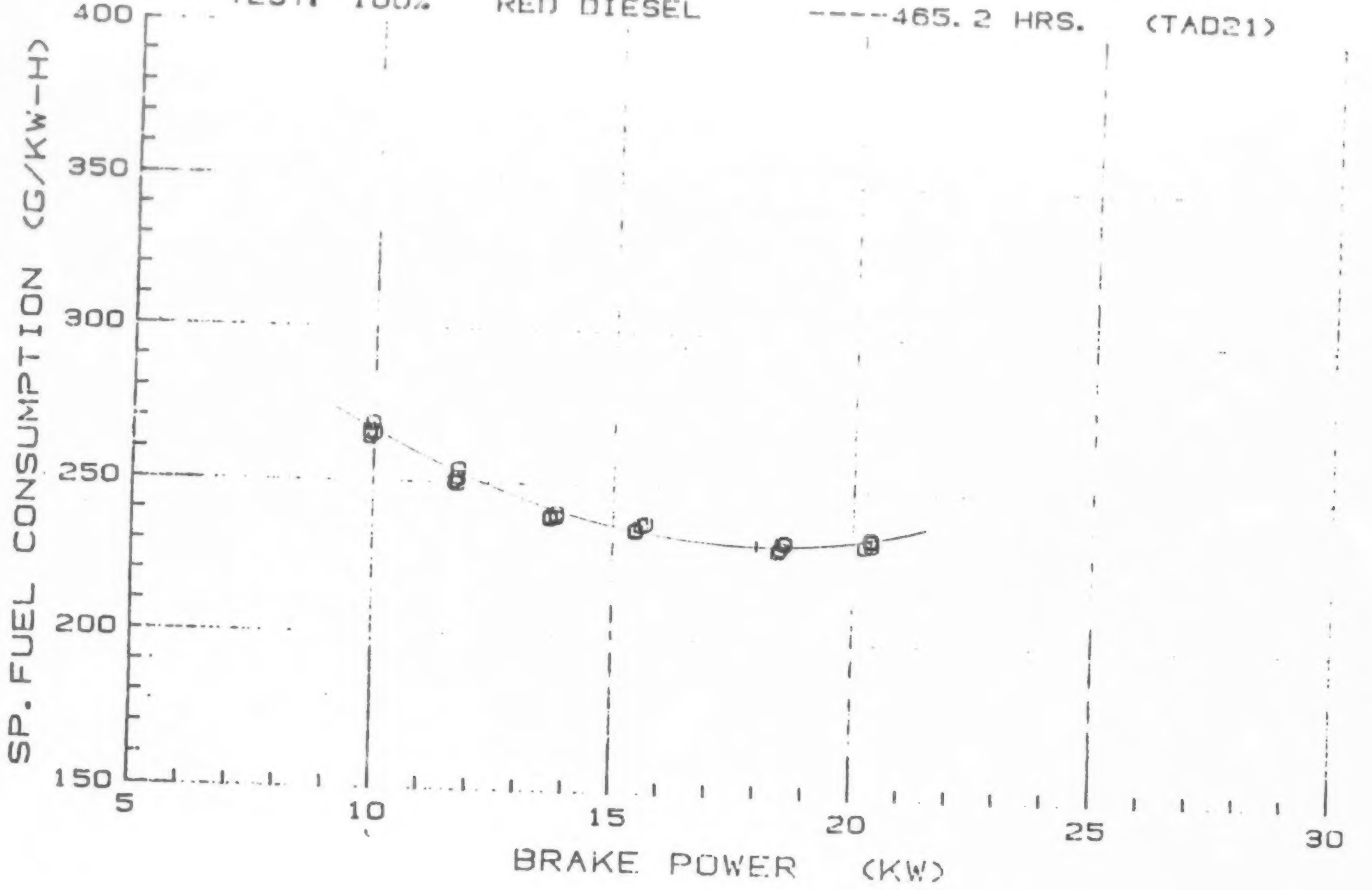
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE, APR. 17.1985 -ENGINE, DEUTZ F2L912 2 CYL.

TEST, 100% RED DIESEL ----465.2 HRS. (TAD21)



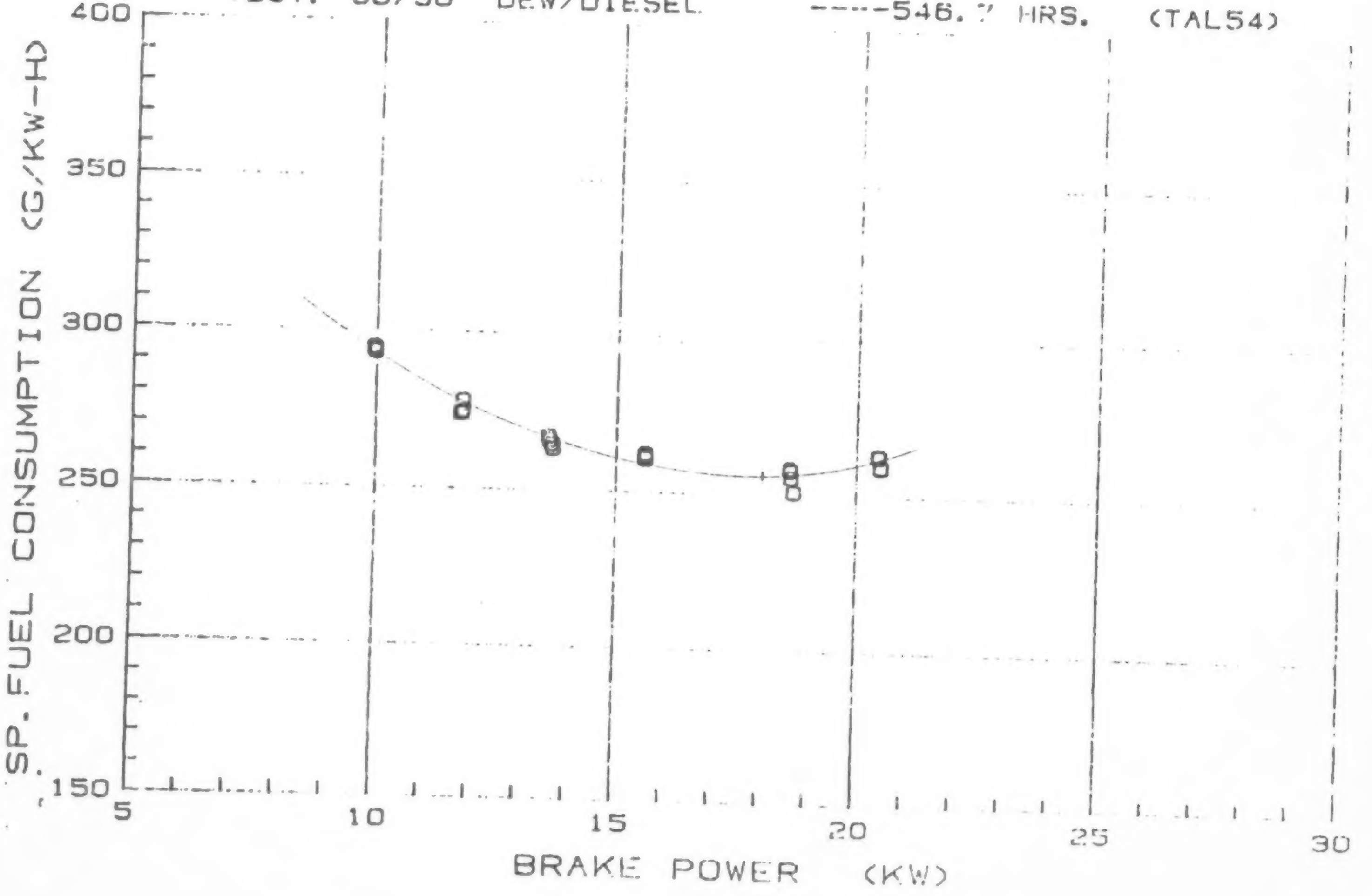
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: APR. 23, 1985 -ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50/50 DEW/DIESEL ----546.7 HRS. (TAL54)



Appendix C

Engine Power Versus Engine Speed

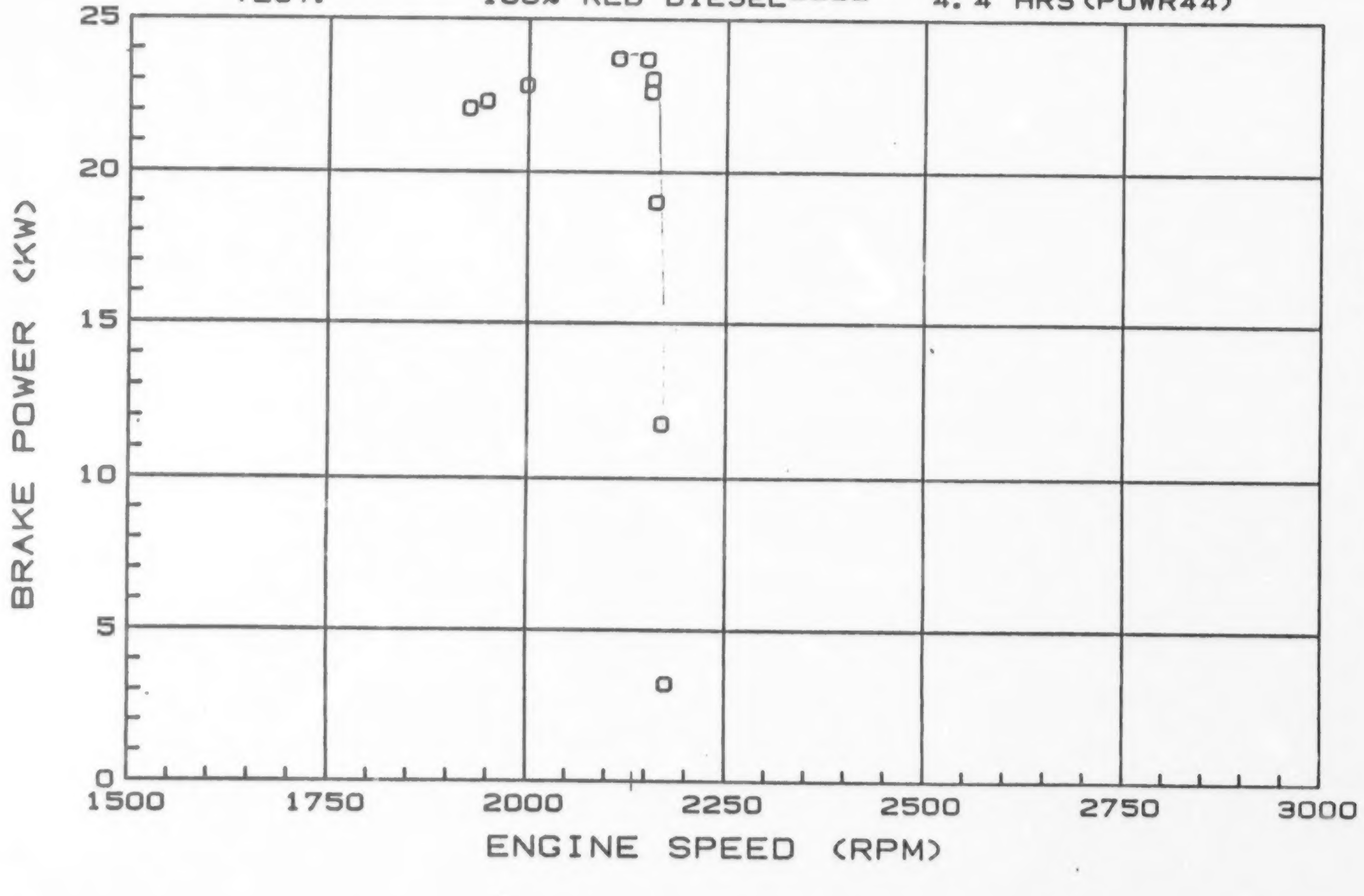
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAR. 20 .1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: 100% RED DIESEL---- 4.4 HRS(POWR44)



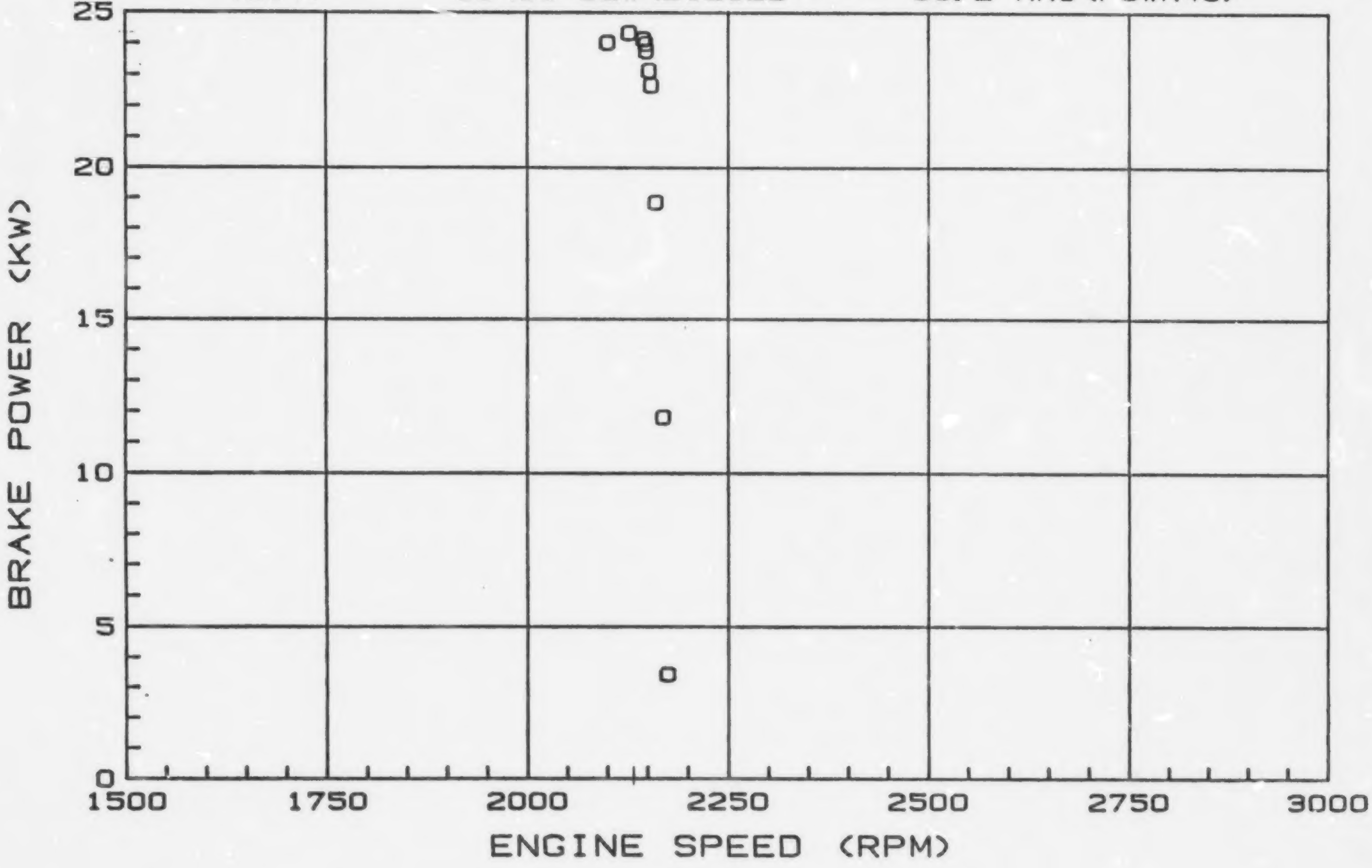
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAR. 22 . 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50\50 DEW\DIESEL---- 36.2 HRS (PCWR45)



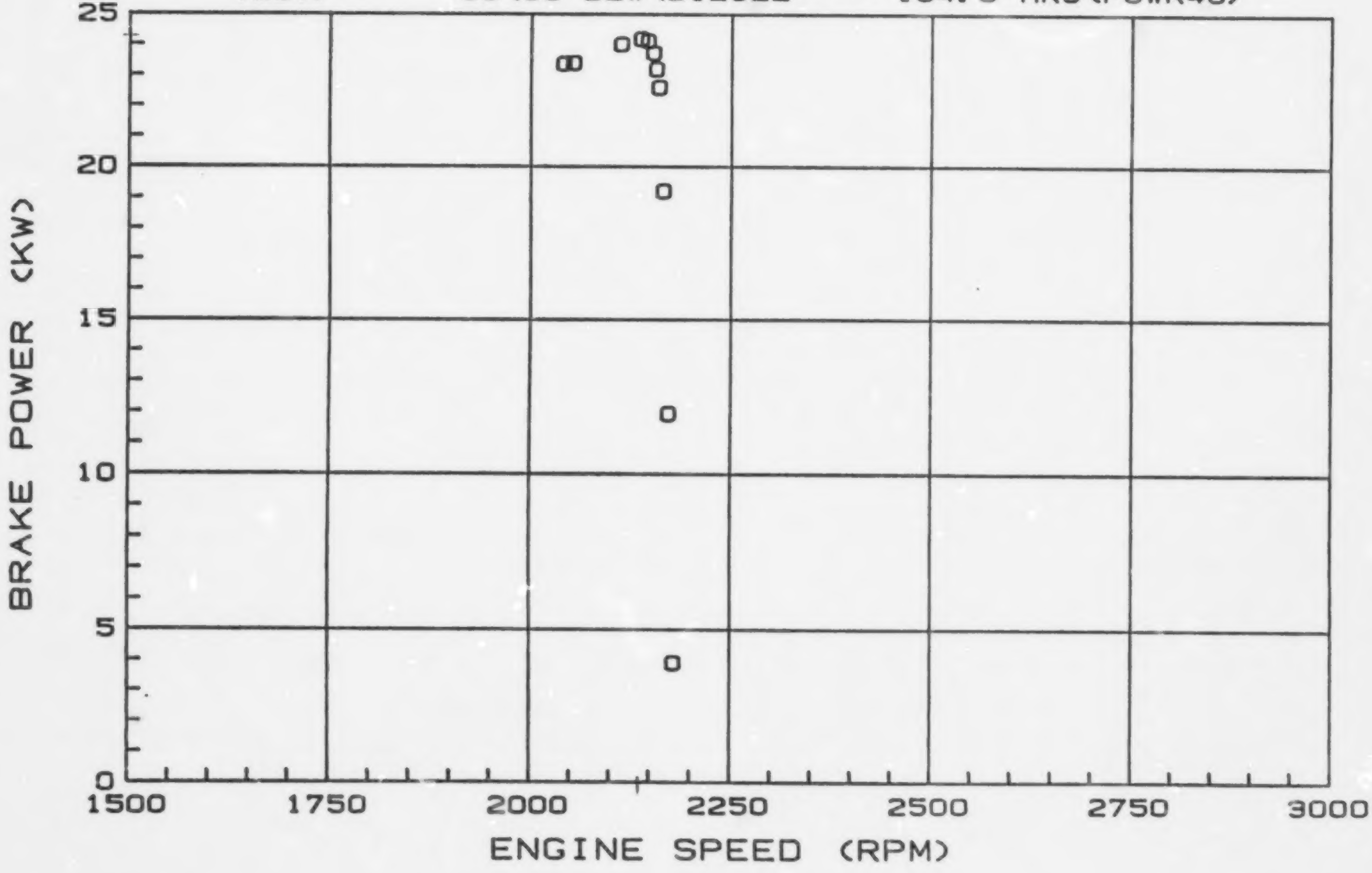
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAR. 28 .1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50\50 DEW\DIESEL---- 134.8 HRS(POWR48)



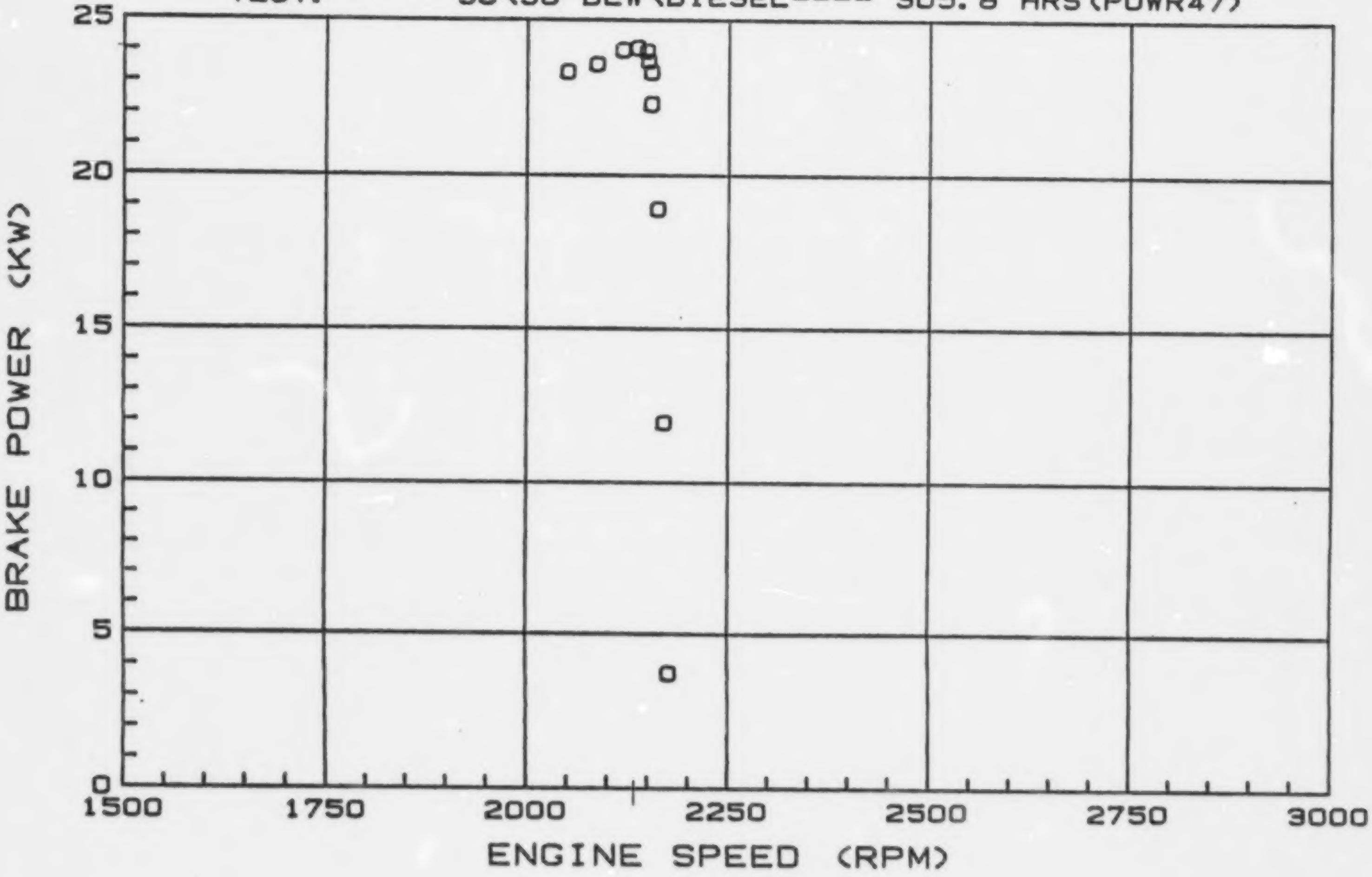
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: APR. 08 , 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50\50 DEW\DIESEL---- 305. 8 HRS (POWR47)



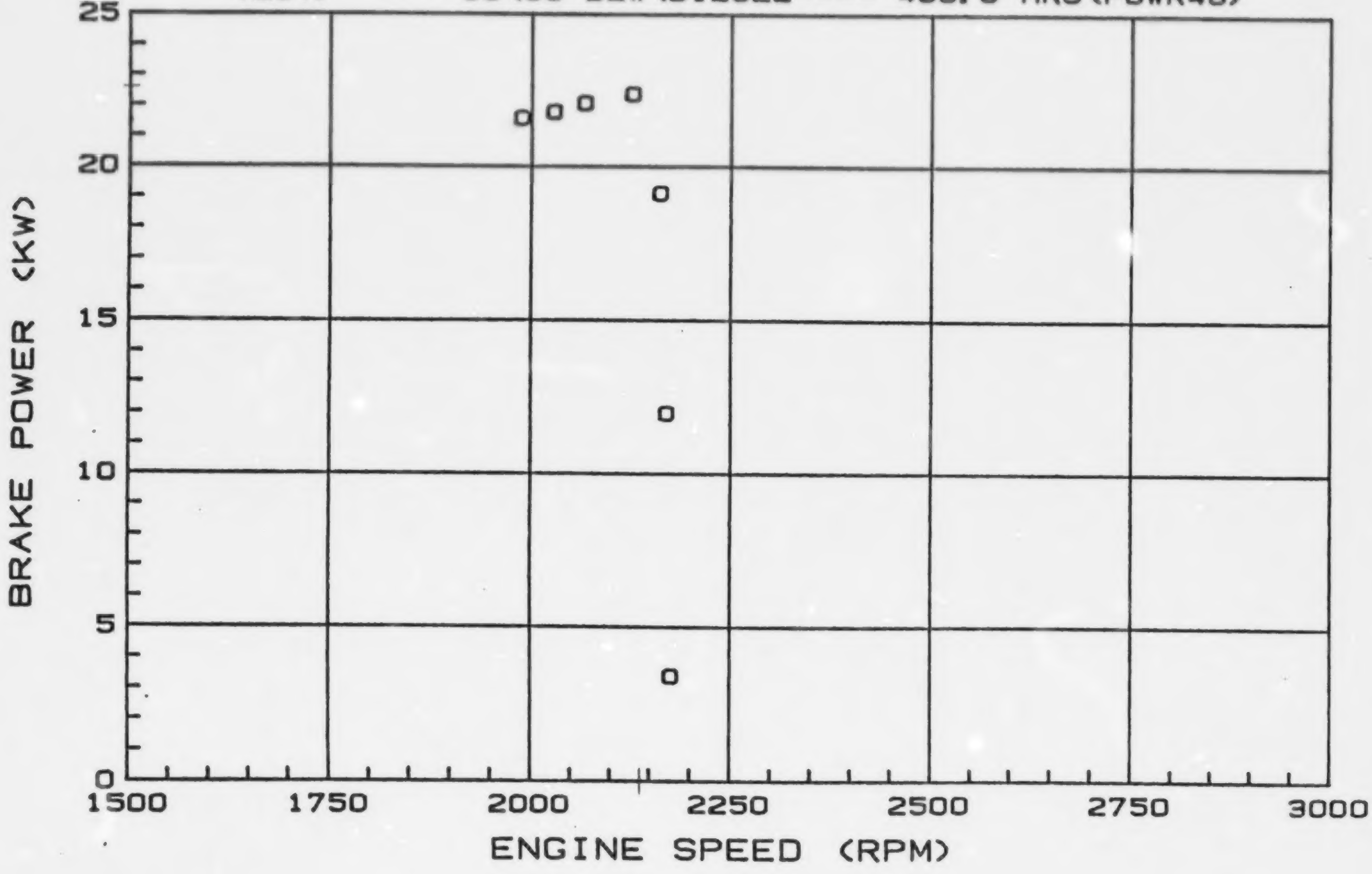
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: APR. 14 , 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50\50 DEW\DIESEL---- 438. 8 HRS (POWR48)



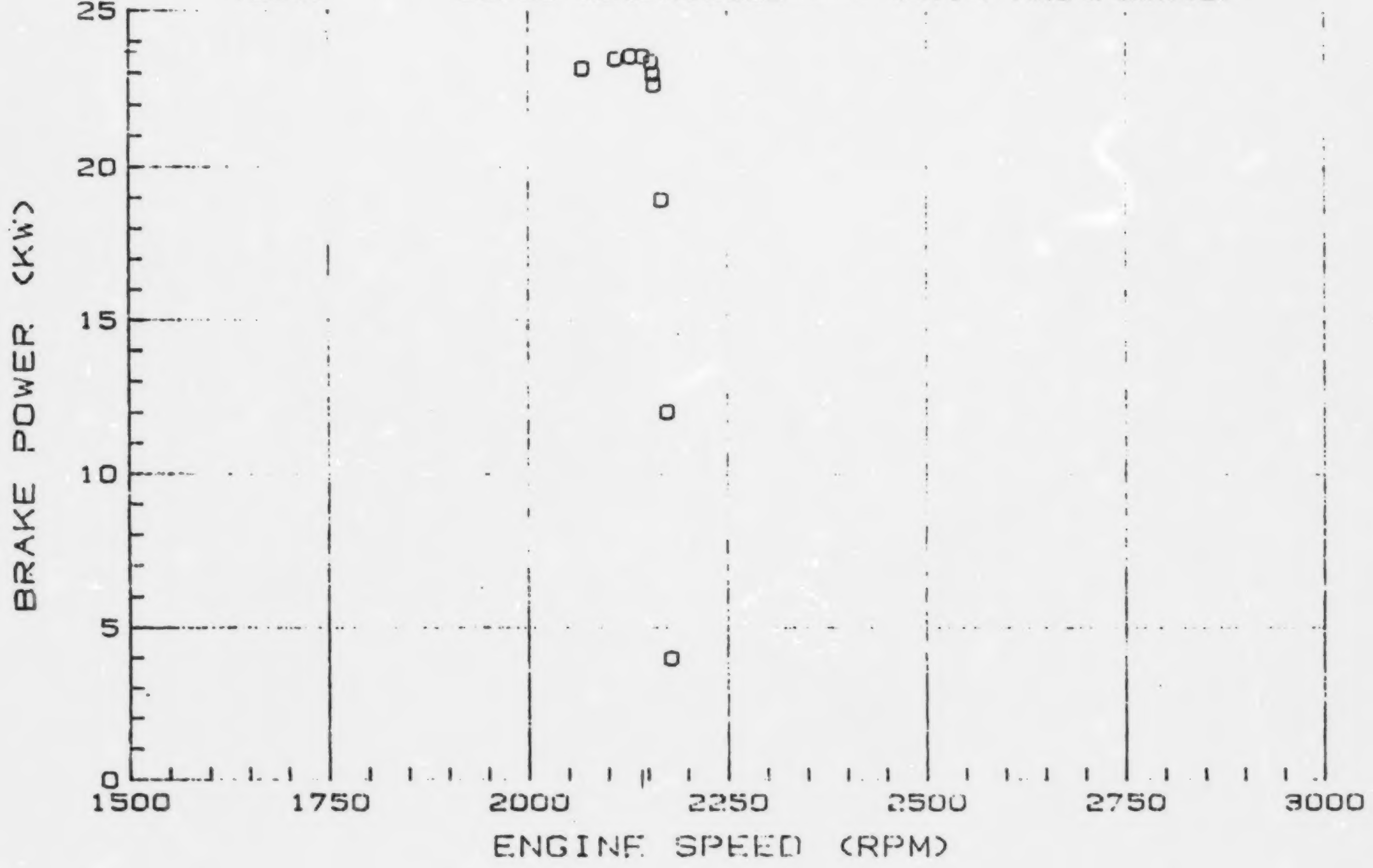
UNIVERSITY OF SASKATCHEWAN--TALL OIL FUEL

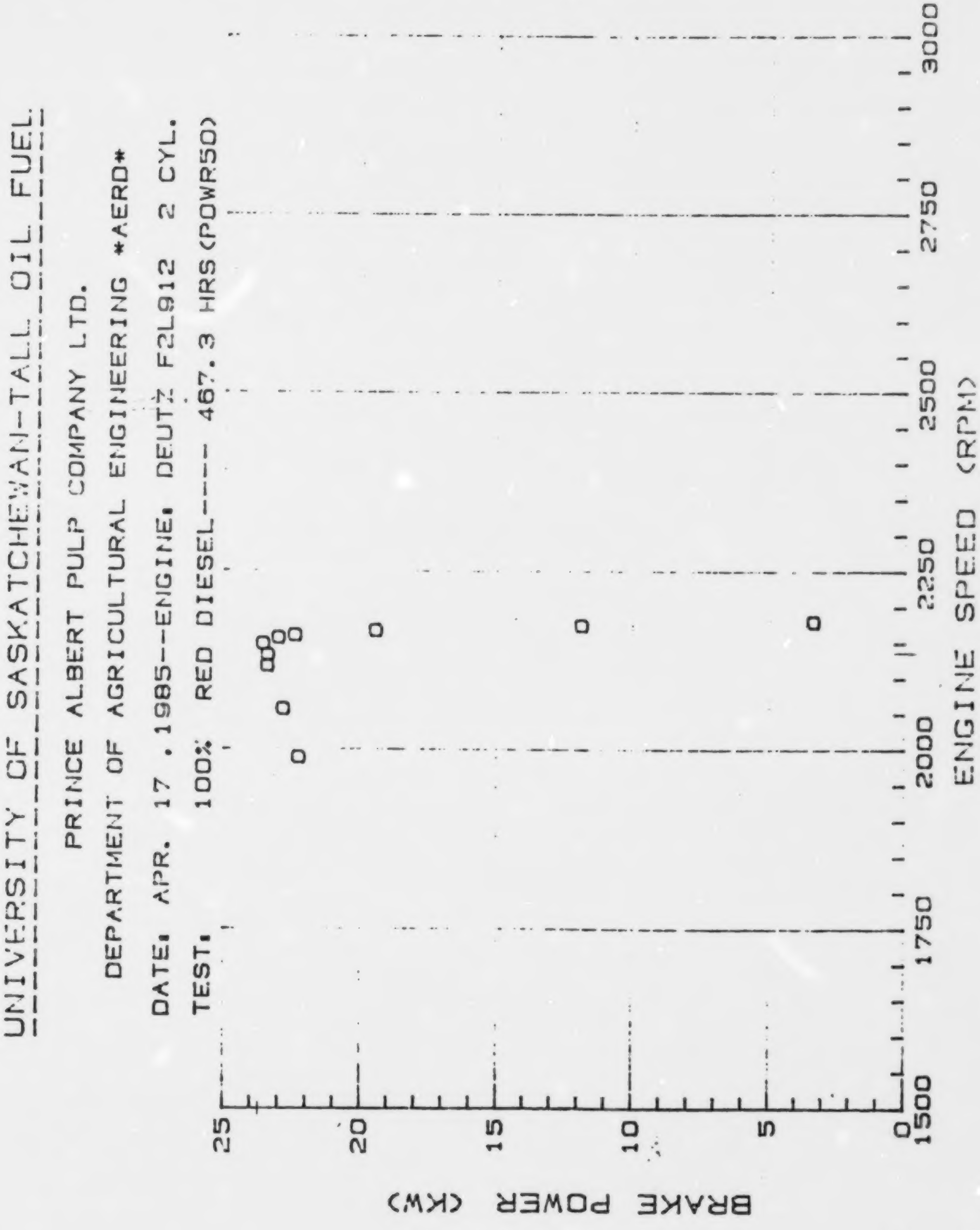
PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: APR. 16 . 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50/50 DEW/DIESEL----- 447.4 HRS (POWR49)





UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE, APR. 17 .1985--ENGINE, DEUTZ F2L912 2 CYL.

TEST, 100% RED DIESEL---- 467.3 HRS(POWR50)

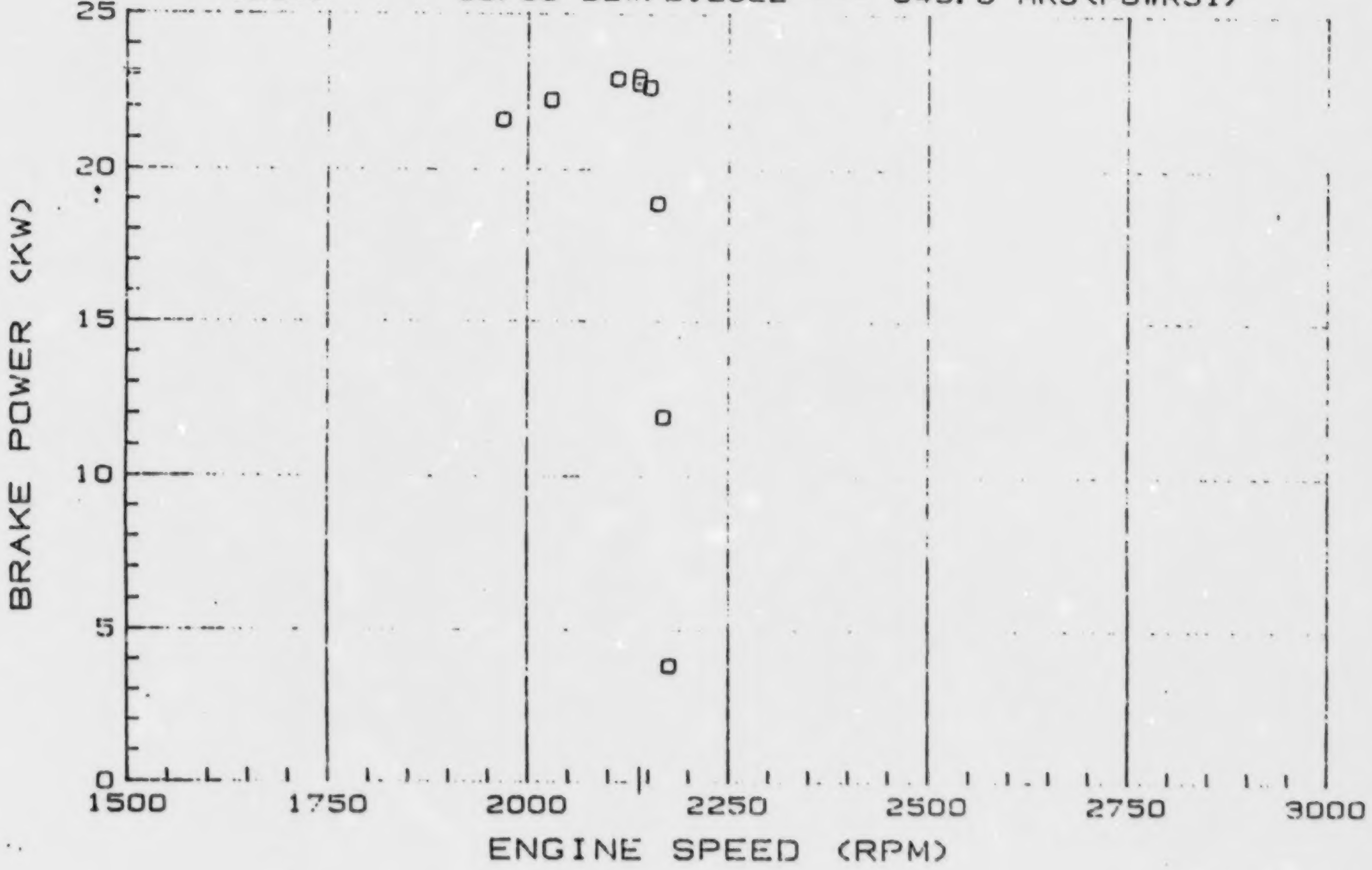
UNIVERSITY OF SASKATCHEWAN--TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE, APR. 23 . 1985--ENGINE, DEUTZ F2L912 2 CYL.

TEST, 50/50 DEW/DIESEL---- 549.0 HRS(POWR51)



Appendix D

Wear Metal Versus Engine Operating Time.

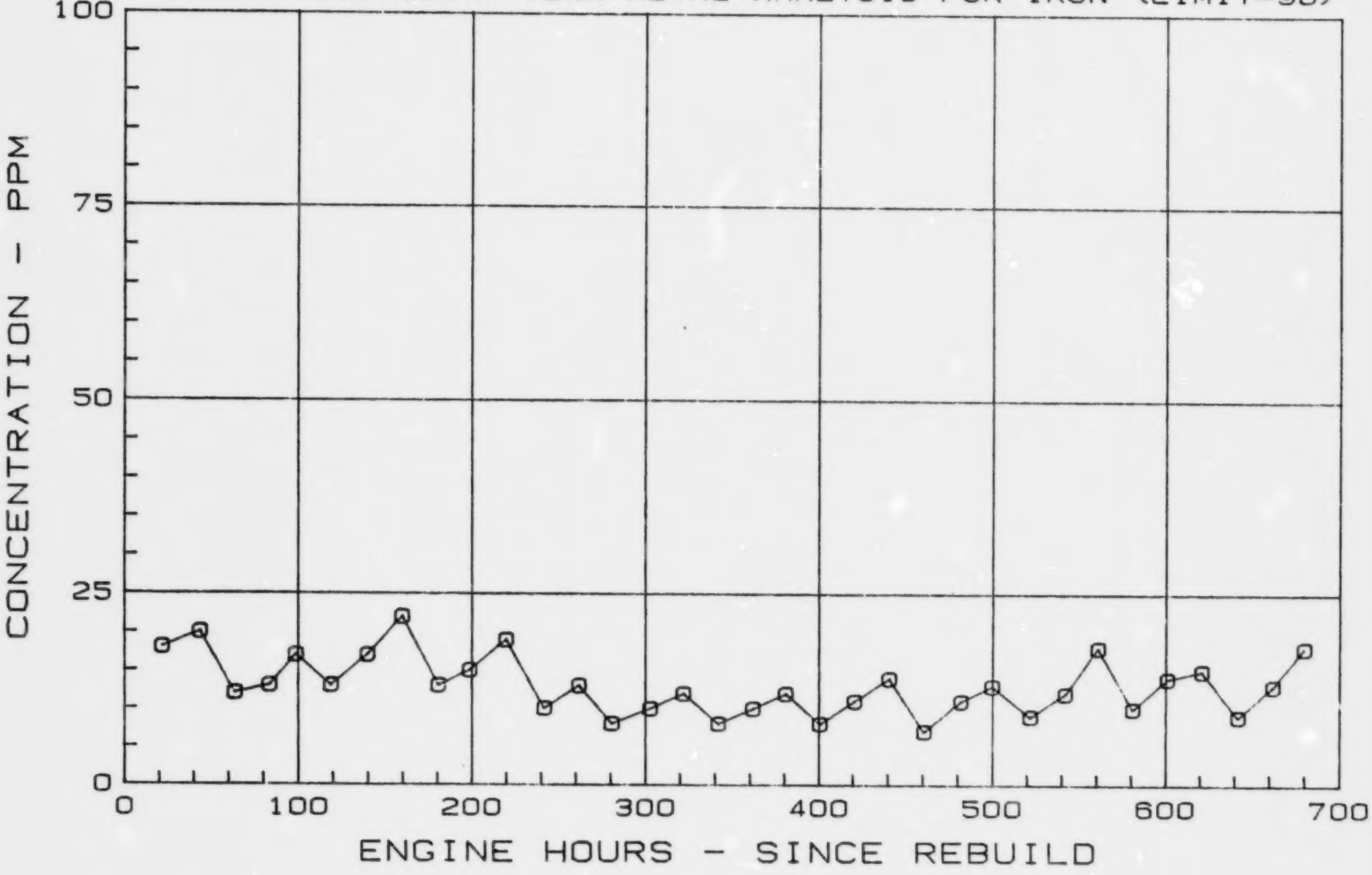
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAY 22 .1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR IRON (LIMIT=90)



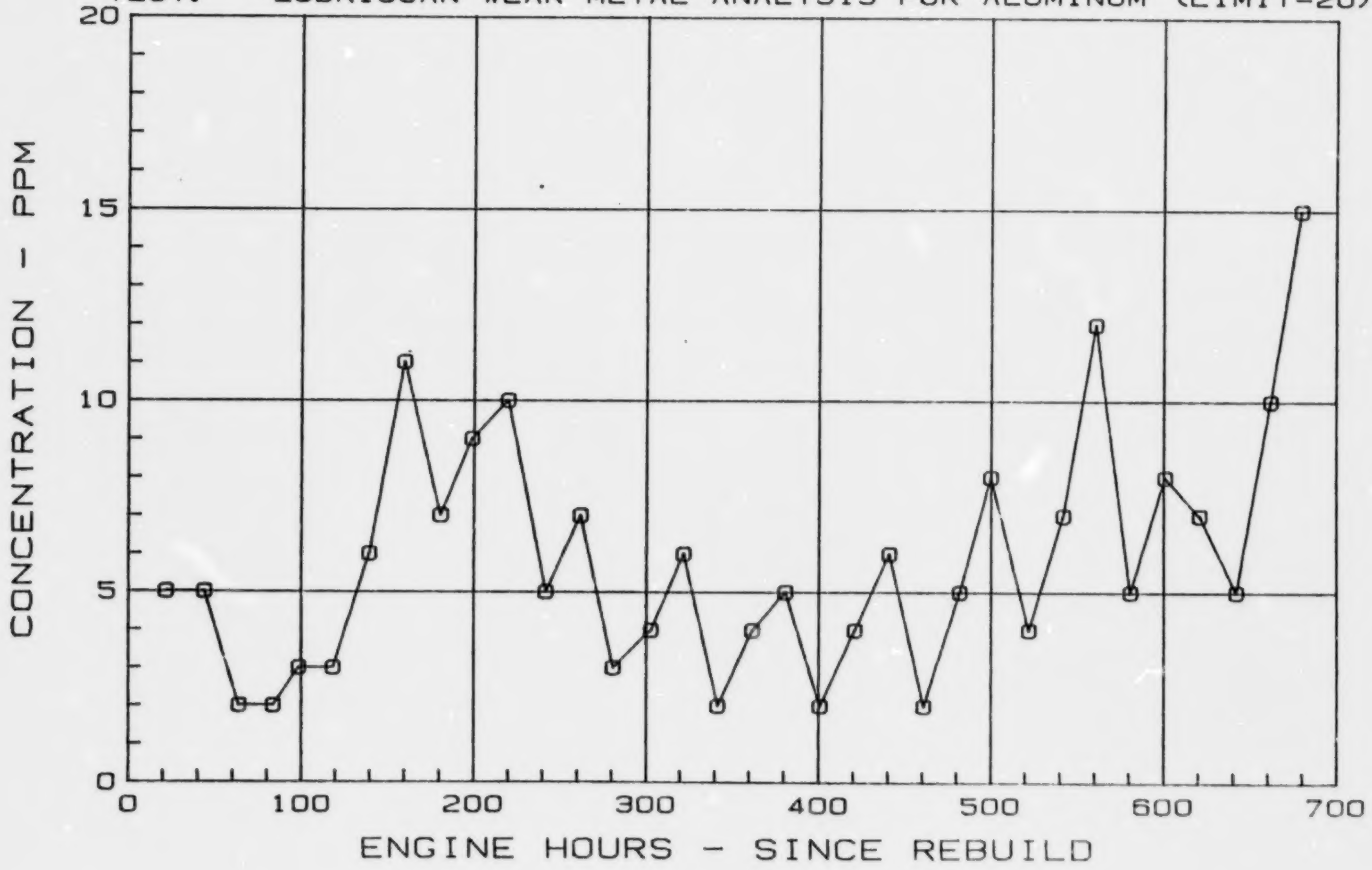
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAY 22 . 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR ALUMINUM (LIMIT=20)



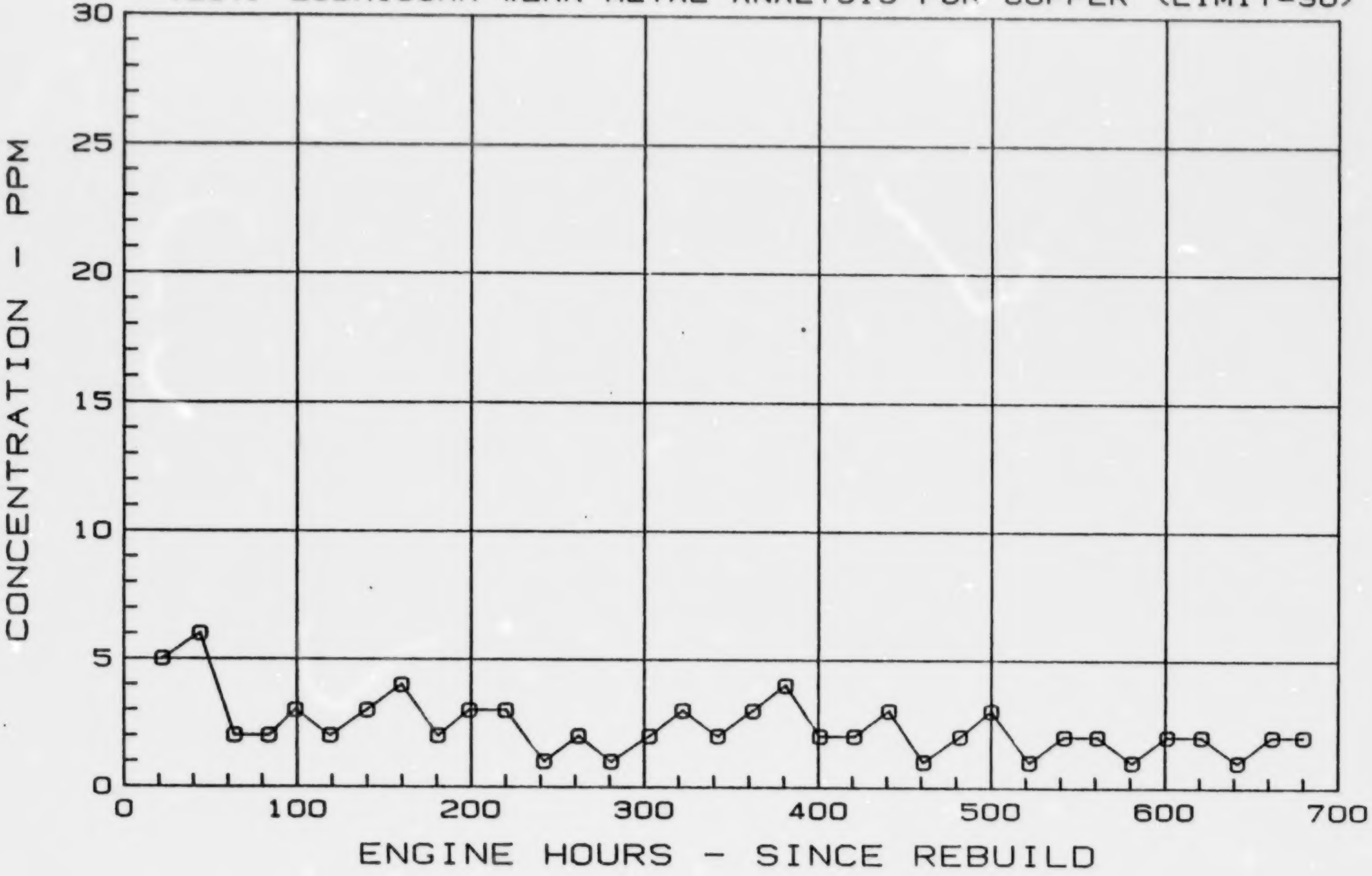
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAY 22 .1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR COPPER (LIMIT=30)



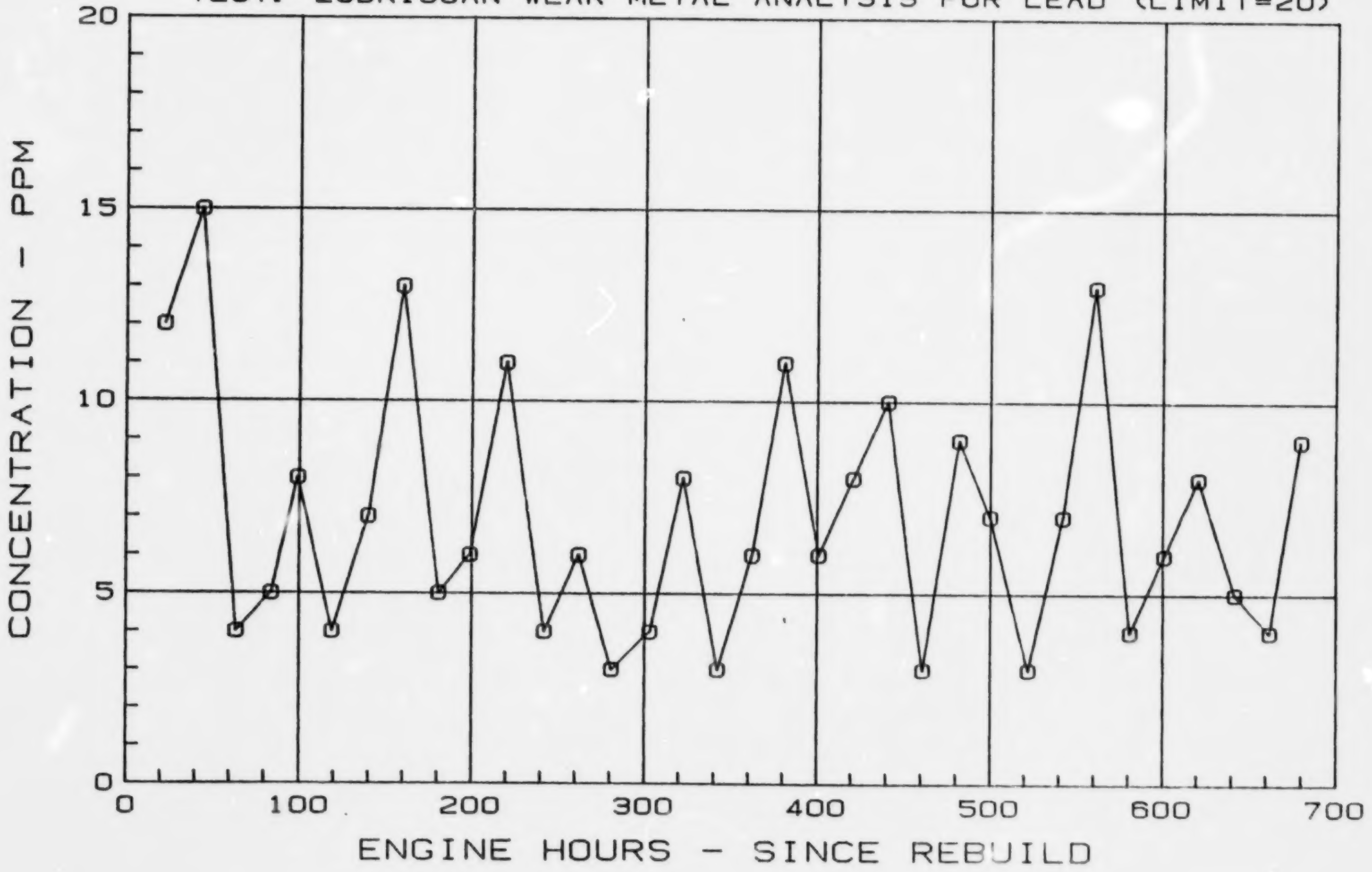
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

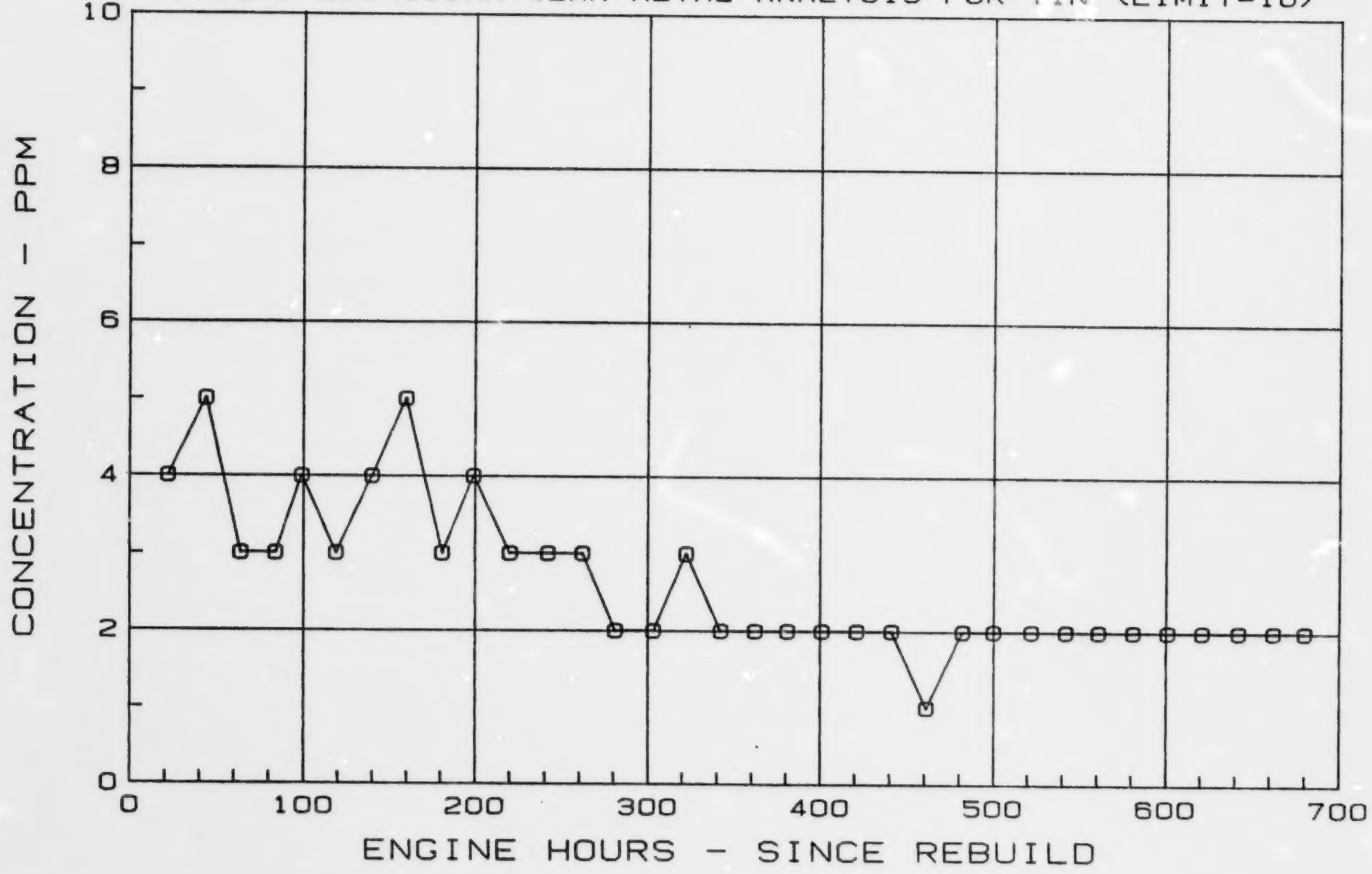
DATE: MAY 22 . 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR LEAD (LIMIT=20)



UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.
DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*
DATE: MAY 22 .1985--ENGINE: DEUTZ F2L912 2 CYL.
TEST: LUBRISCAN WEAR METAL ANALYSIS FOR TIN (LIMIT=10)



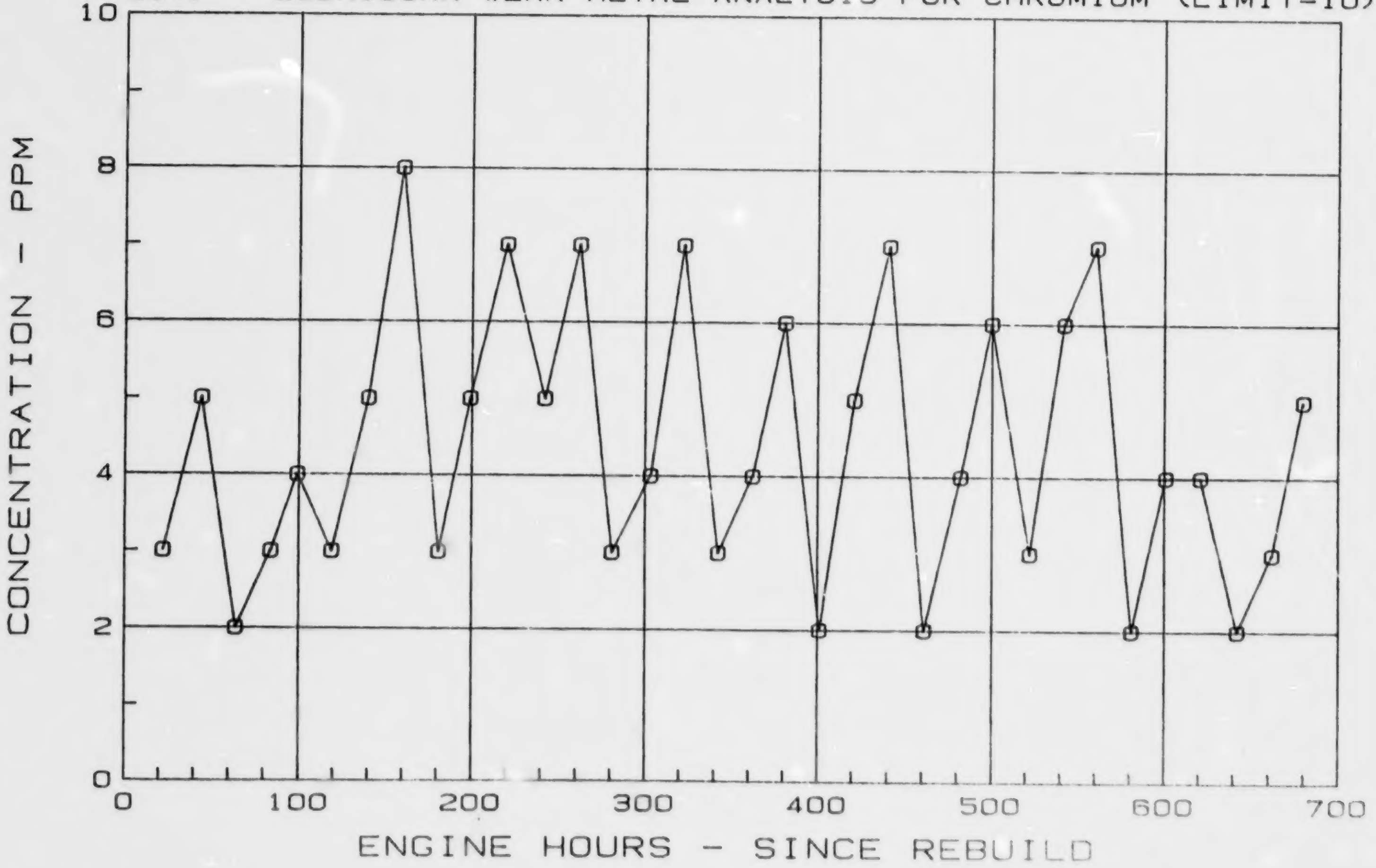
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAY 22 .1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR CHROMIUM (LIMIT=10)



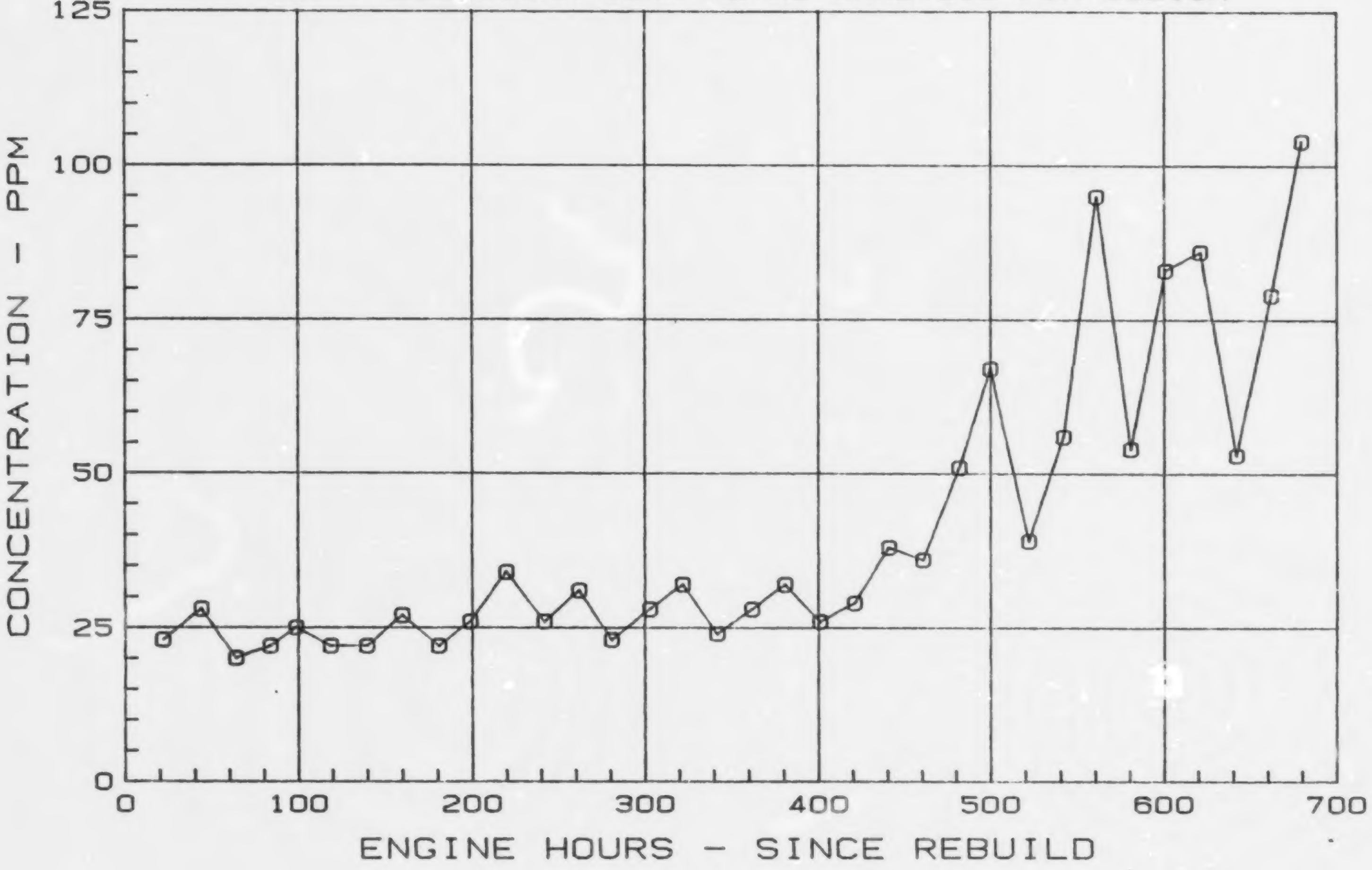
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

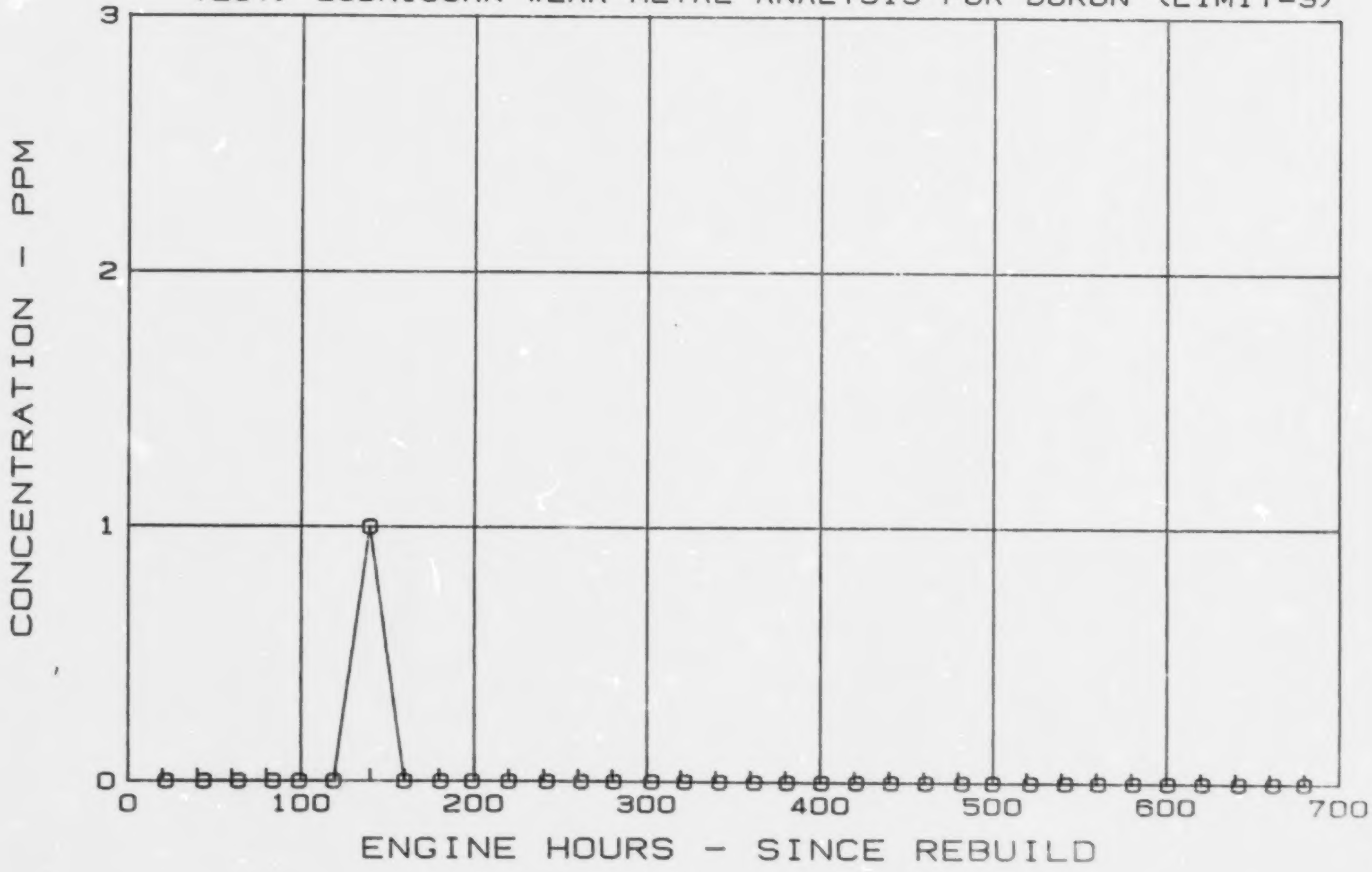
PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAY 22 .1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR SODIUM





UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAY 22 , 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR BORON (LIMIT=3)

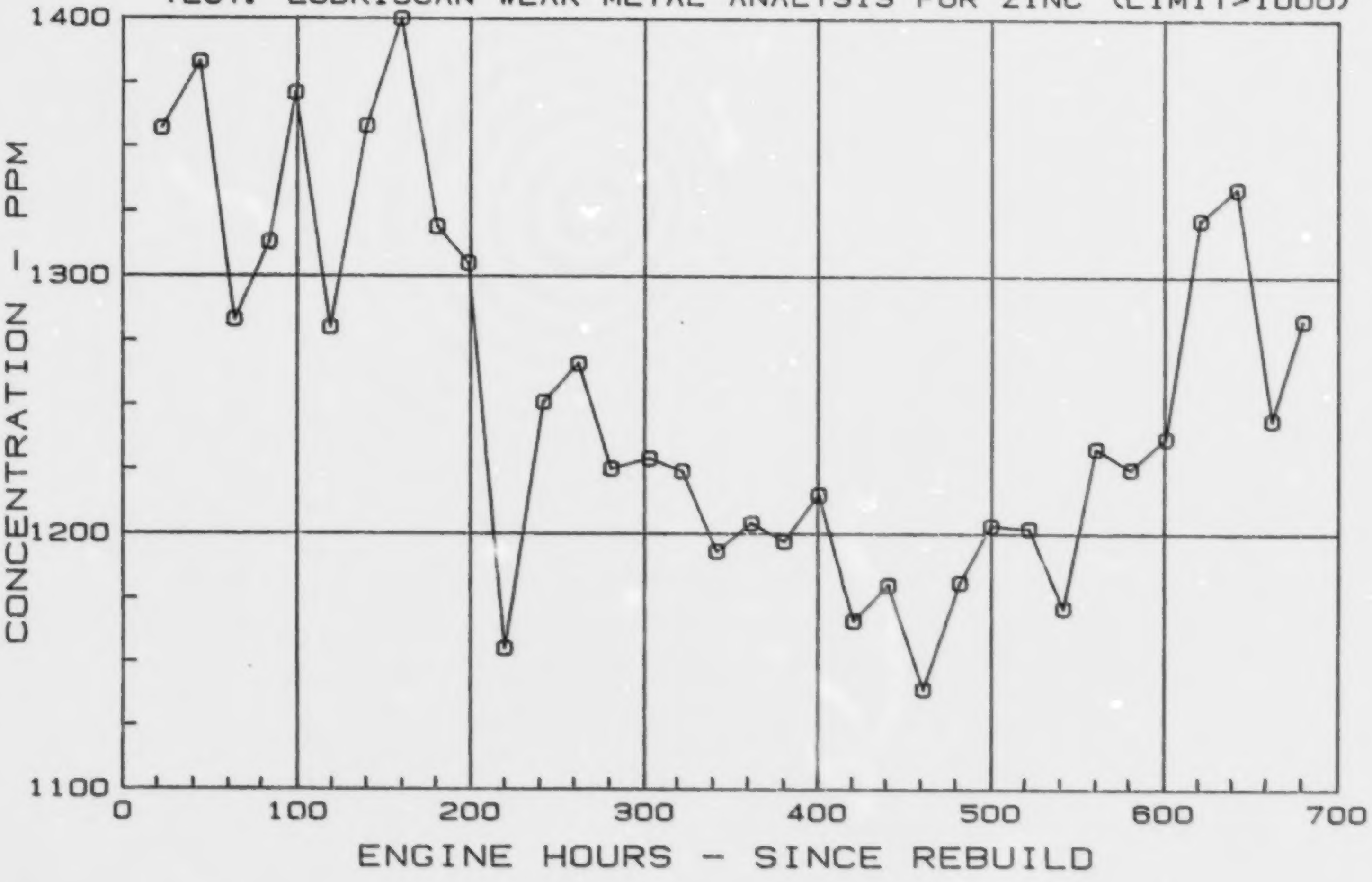
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. MAY 22 . 1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. LUBRISCAN WEAR METAL ANALYSIS FOR ZINC (LIMIT>1000)



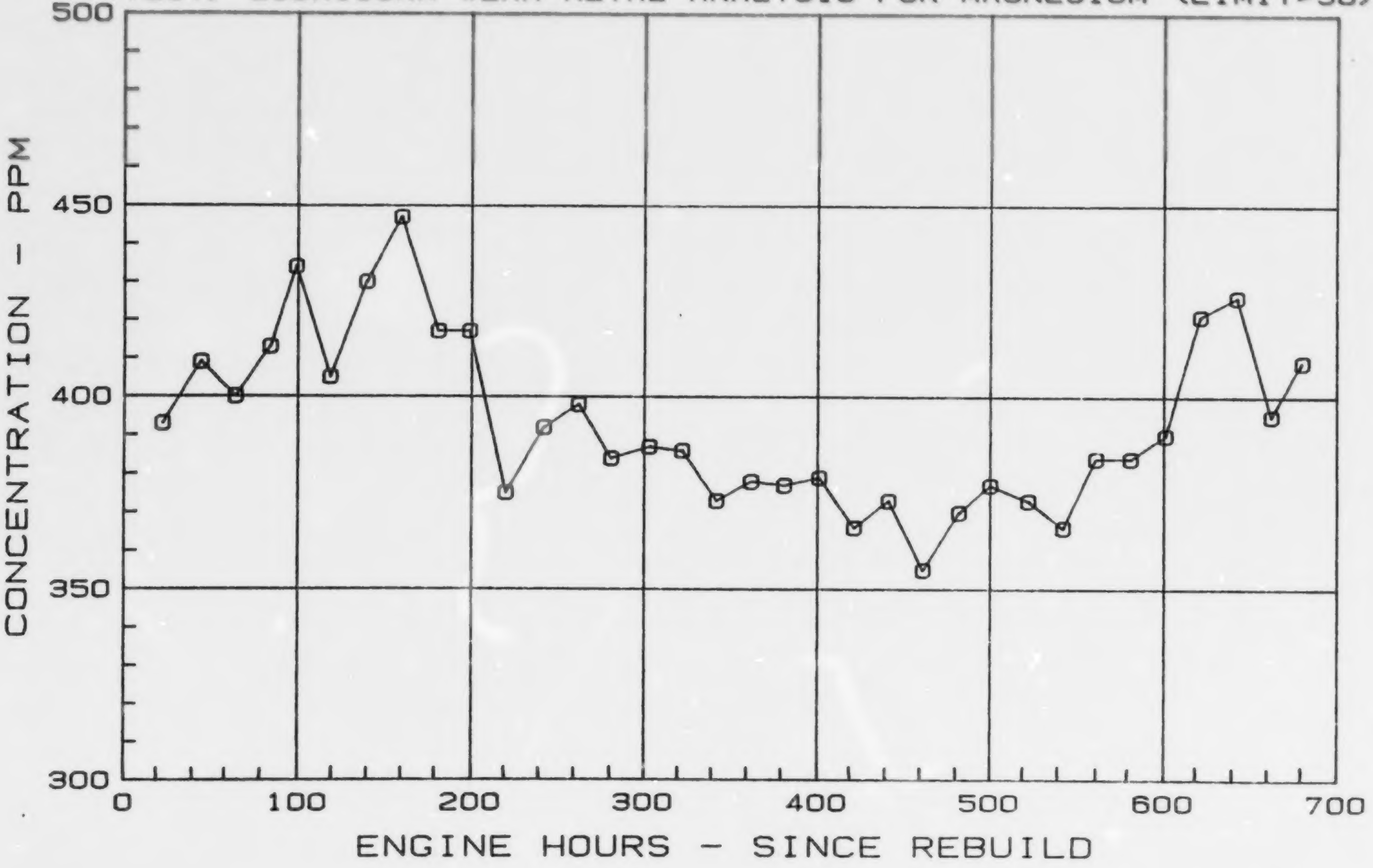
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. MAY 22 , 1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. LUBRISCAN WEAR METAL ANALYSIS FOR MAGNESIUM (LIMIT>50)



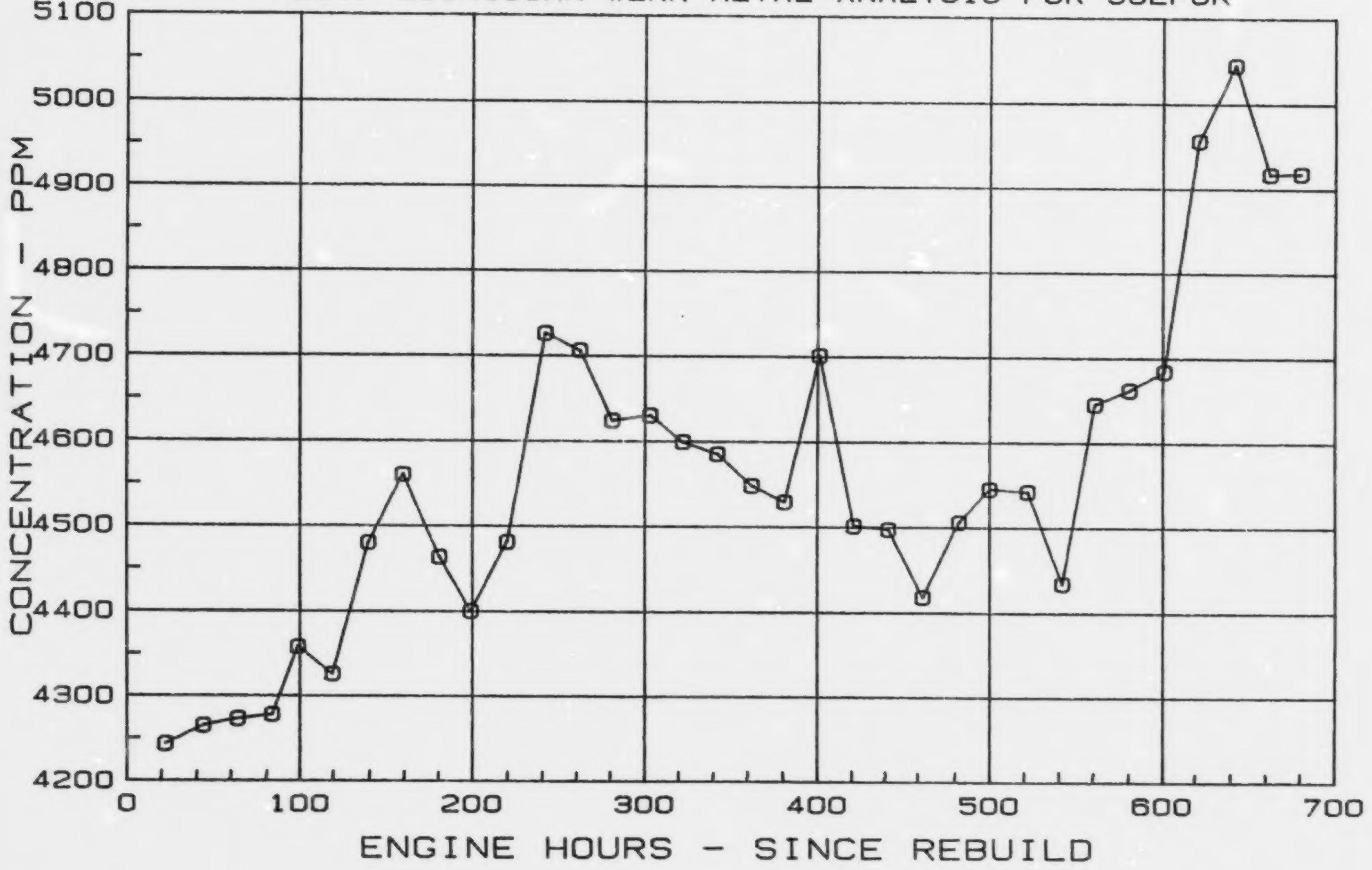
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAY 22 . 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR SULFUR



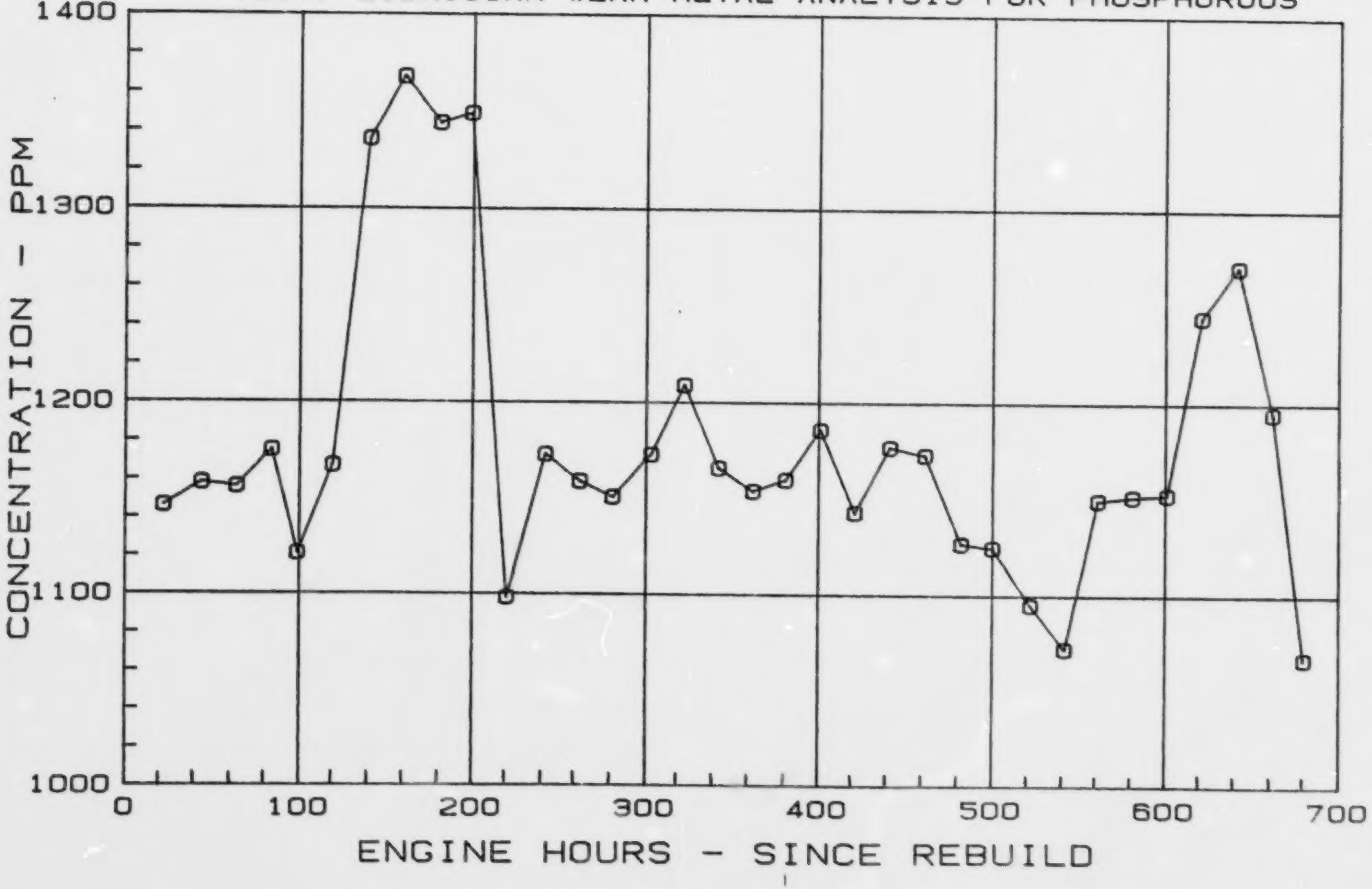
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAY 22 . 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR PHOSPHOROUS



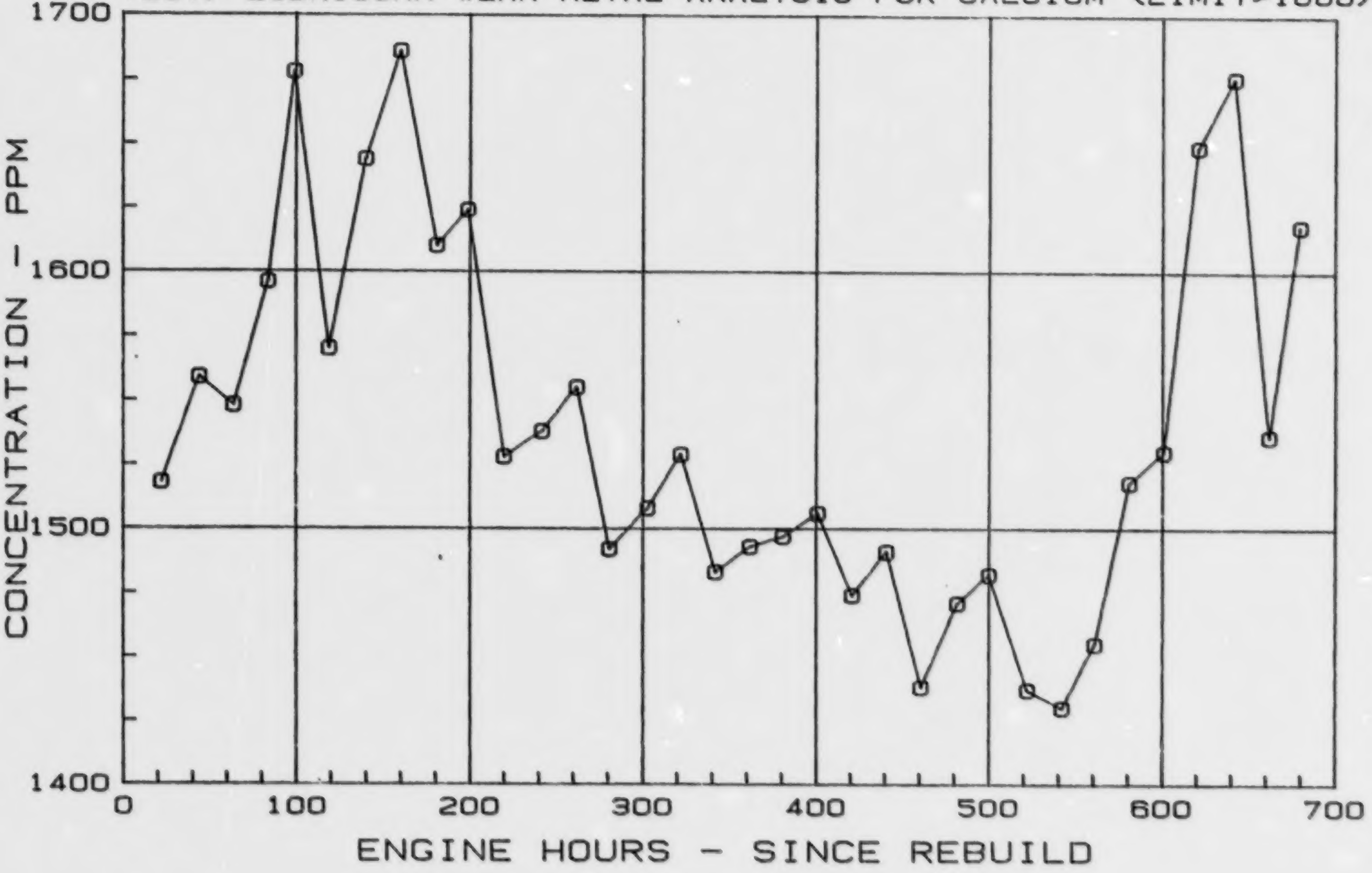
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. MAY 22 . 1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. LUBRISCAN WEAR METAL ANALYSIS FOR CALCIUM (LIMIT>1000)



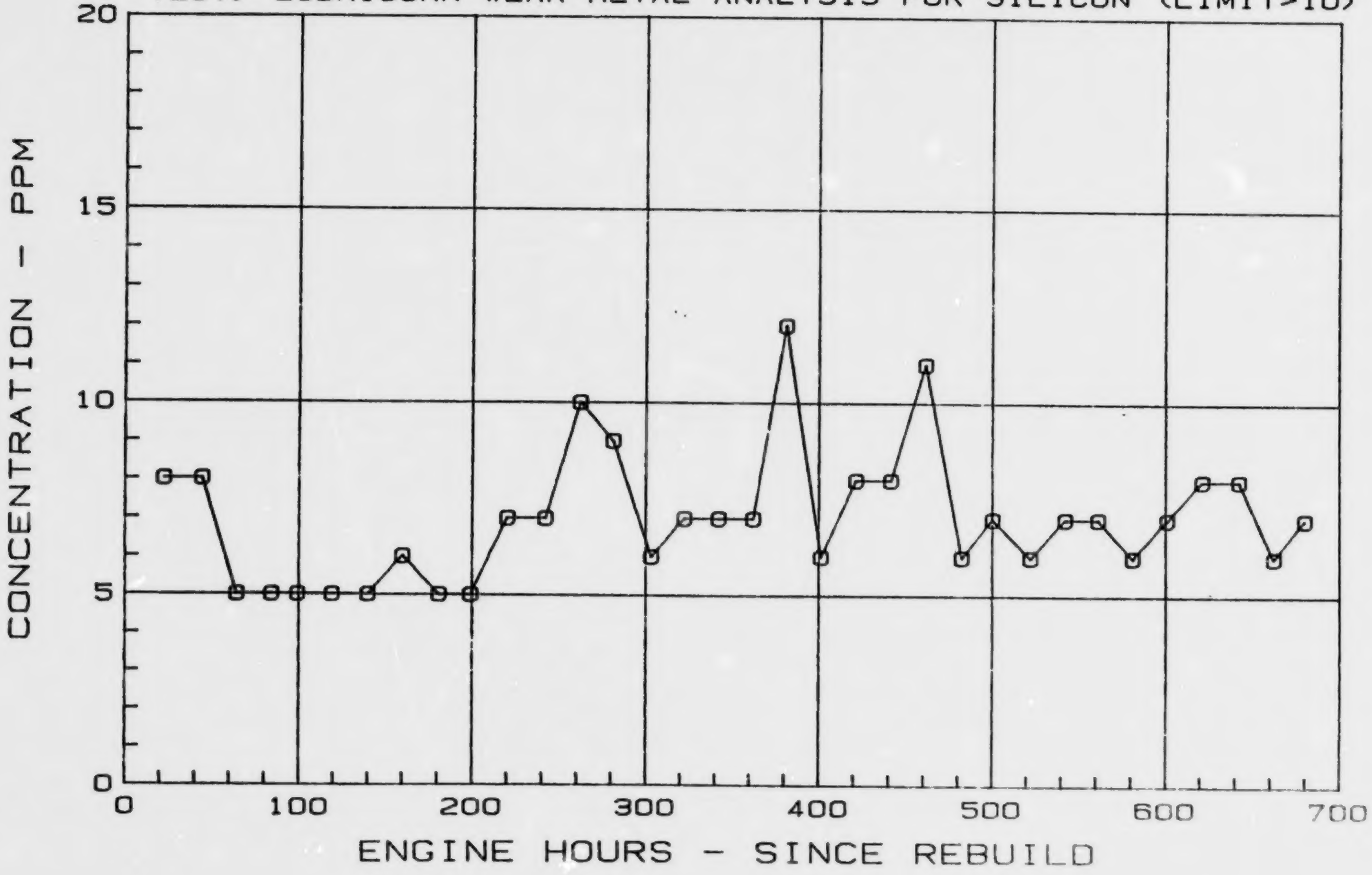
UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

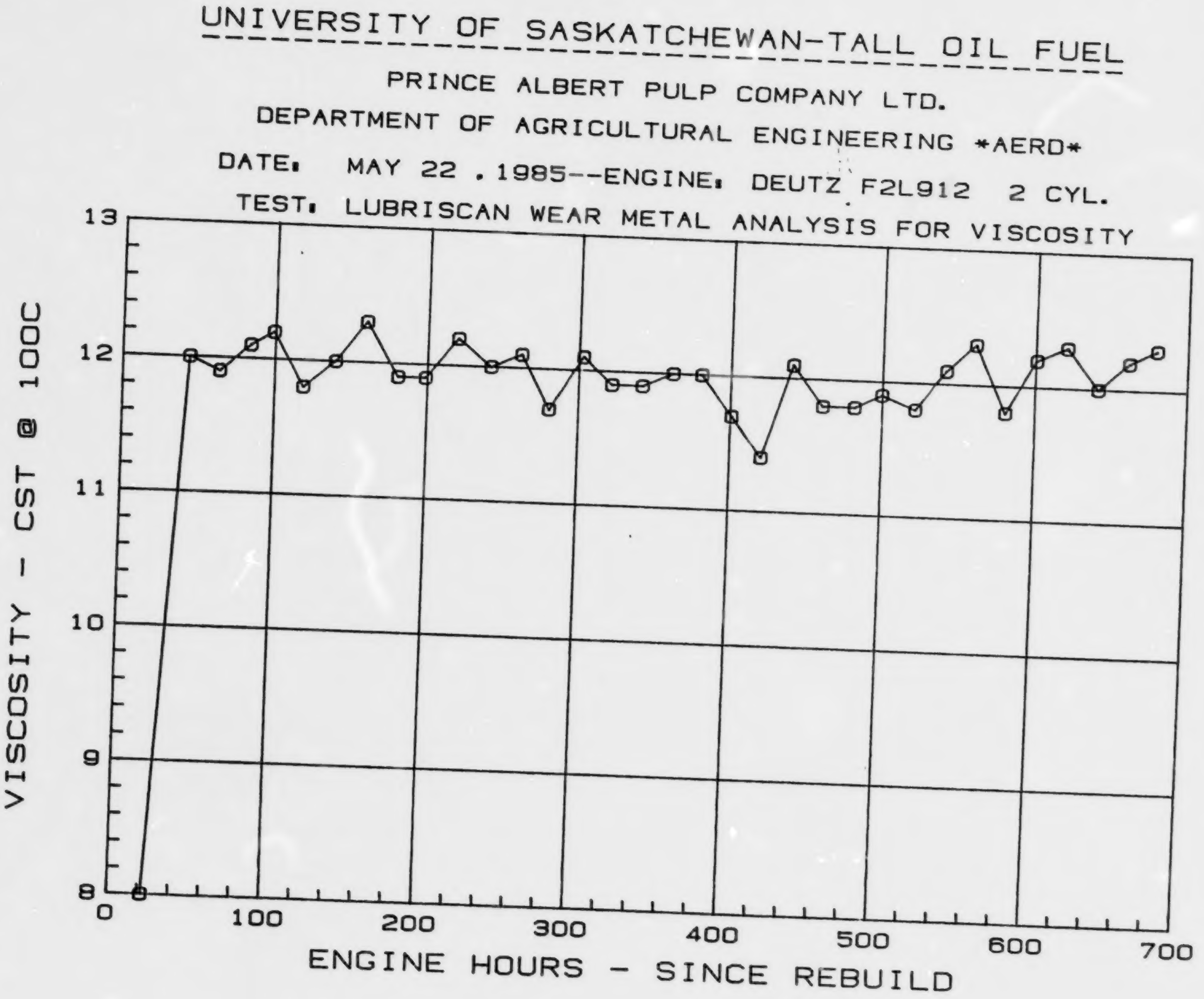
PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAY 22 .1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR SILICON (LIMIT>10)





UNIVERSITY OF SASKATCHEWAN-TALL OIL FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAY 22 .1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR VISCOSITY

APPENDIX IV

INSPECTION OF FUEL INJECTOR PLUNGER CORROSION

The University of Saskatchewan sub-contracted Dr. Ian Peggs of Hanson Materials Engineering (Western) Limited, to evaluate any surface damage which had occurred on the plungers from an in-line Bosch fuel injection pump. These parts had been used in the Deutz F2L 912 engine during the first long term test. In this test, the engine was operated for 580 hours using a blend of 50% dewatered tall oil and 50% diesel.

The following is a copy of Dr. Peggs' report.

hanson materials engineering
consulting engineers
7450 - 18 street, edmonton, alberta, canada T6P 1N8
Tel. (403) 464-7916 (24 hours) Telex 037-3755 Telefax (403) 464-4175

August 19,1985

University of Saskatchewan
Saskatoon, Saskatchewan
S7N OWO

Attention: W.D. Read, P. Eng.

Subject: Inspection of Fuel Injector Plunger Corrosion.

Introduction:

Further to our previous reports dated Nov. 6/84 and Dec. 20/84, for Secor and Associates you submitted an additional two injector plungers and barrels on July 23, 1985 for similar inspection. One unit was identified with two scribe marks and thus they will be referred to as number 1 and number 2, the latter with the marks.

Edmonton ☐ Calgary ☐ Vancouver ☐ Dartmouth ☐ Kamloops ☐ Campbell River ☐ Nanaimo ☐ Fort St. John
Terrace ☐ Prince George ☐ Fort McMurray ☐ Regina ☐ Osaka, Japan

Observations:

The as received injector units are shown in Figure 1.

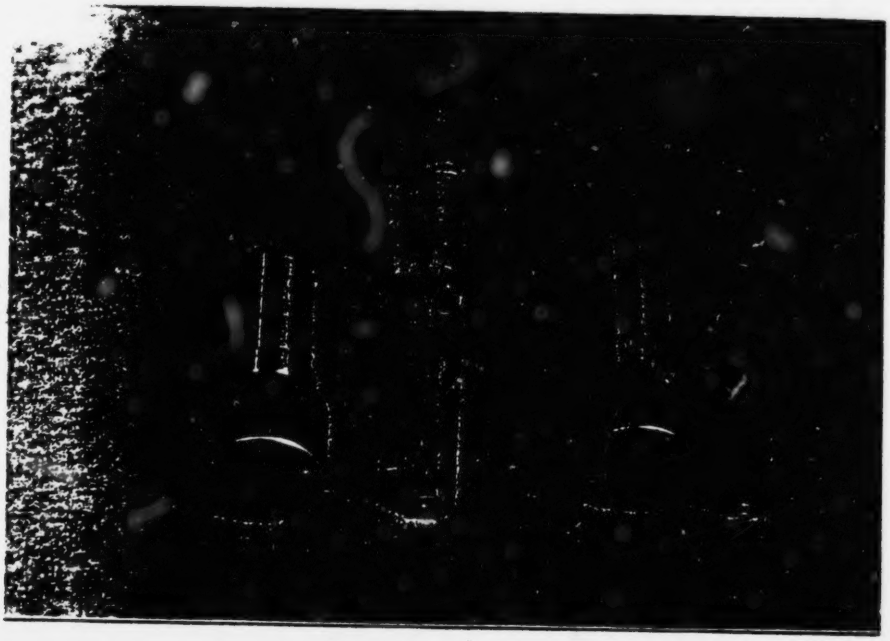


Figure 1.
AS RECEIVED INJECTOR UNITS

The corrosion band on each is shown more closely in Figure 2. Number 2 appears to be more corroded than number 1.

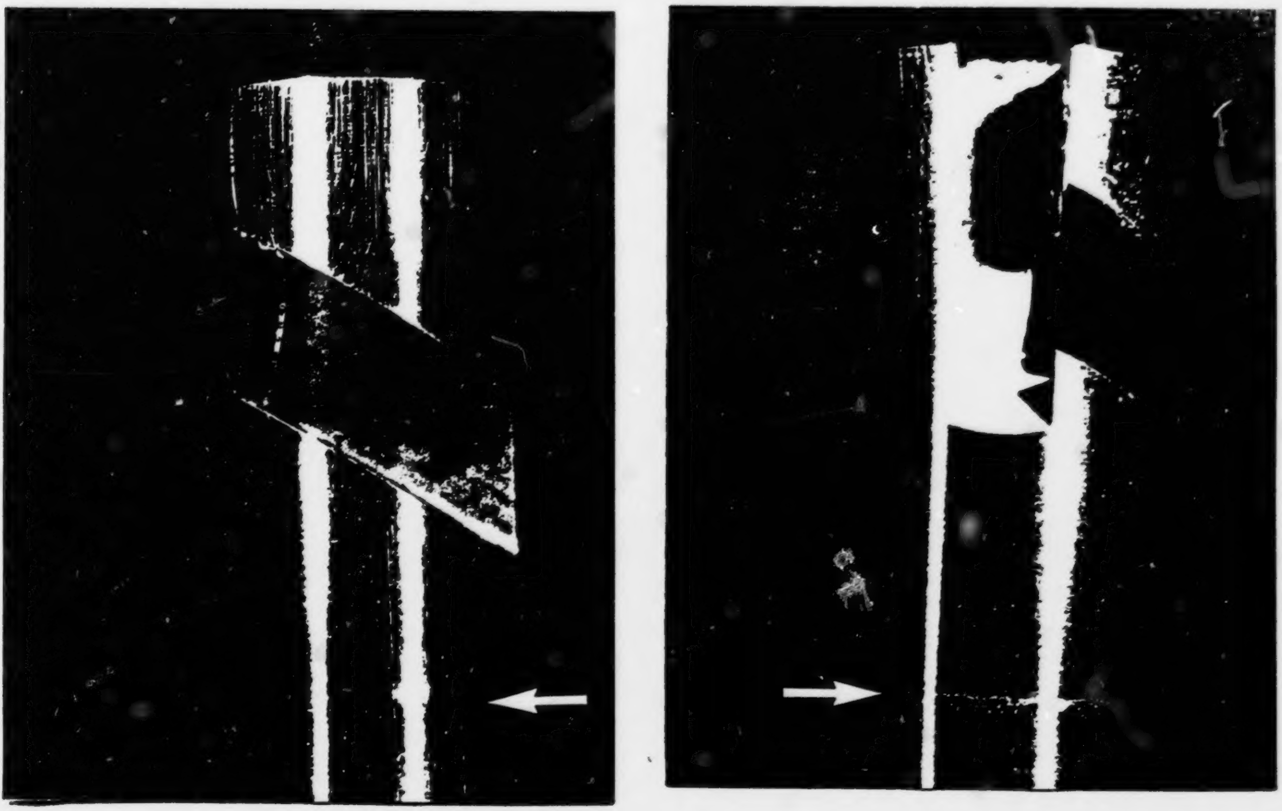


FIGURE 2. MAG. X 7.
CORROSION BANDS, ARROWED, ON
#1, LEFT AND #2, RIGHT PLUNGER.

However, when the surfaces were examined in the scanning electron microscope it was evident that, in general, #1 was more pitted than #2; Figure 3.

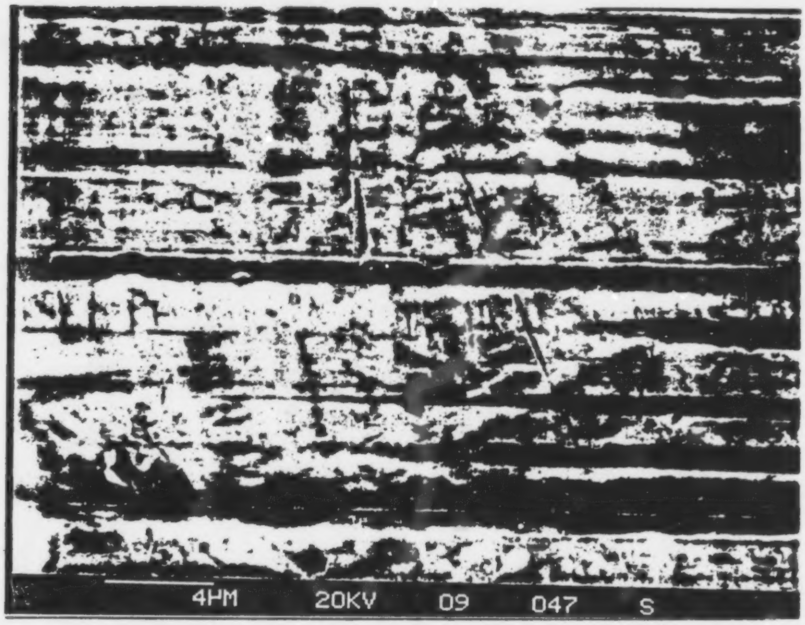


FIGURE 3. MAG. X 3750.
PLUNGER SURFACES
#1 AS MACHINED

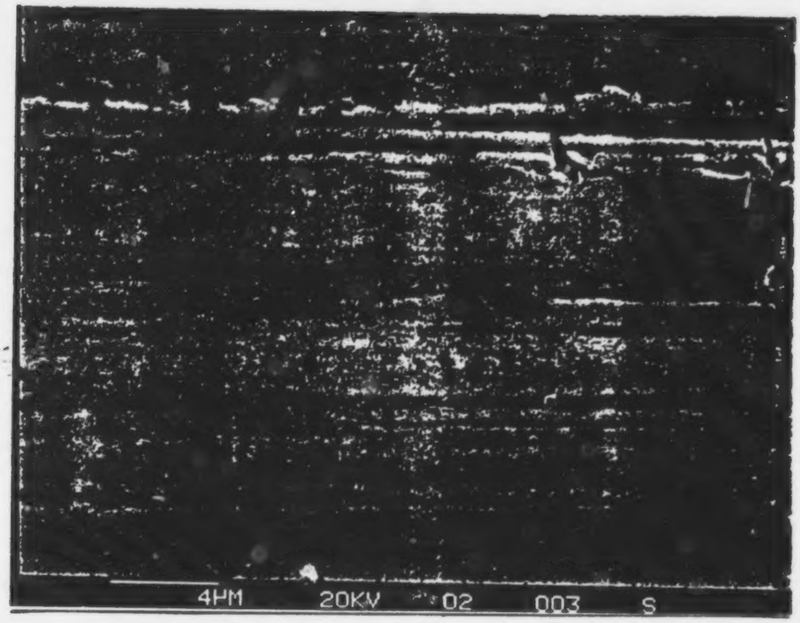

4PM
20KV
02
003
S

FIGURE 3. MAG. X 3750.
PLUNGER SURFACES.
#2 AS MACHINED

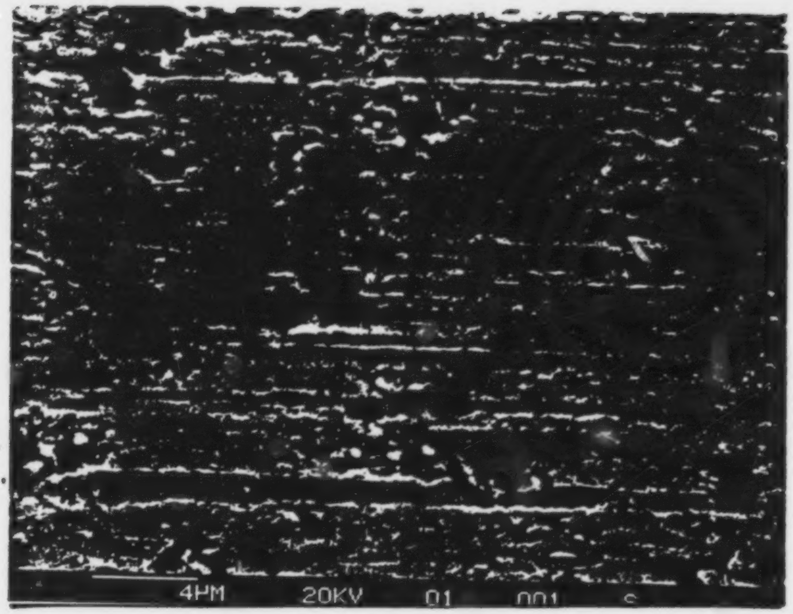

4PM
20KV
01
001
S

FIGURE 4.

#1 CORROSION BAND

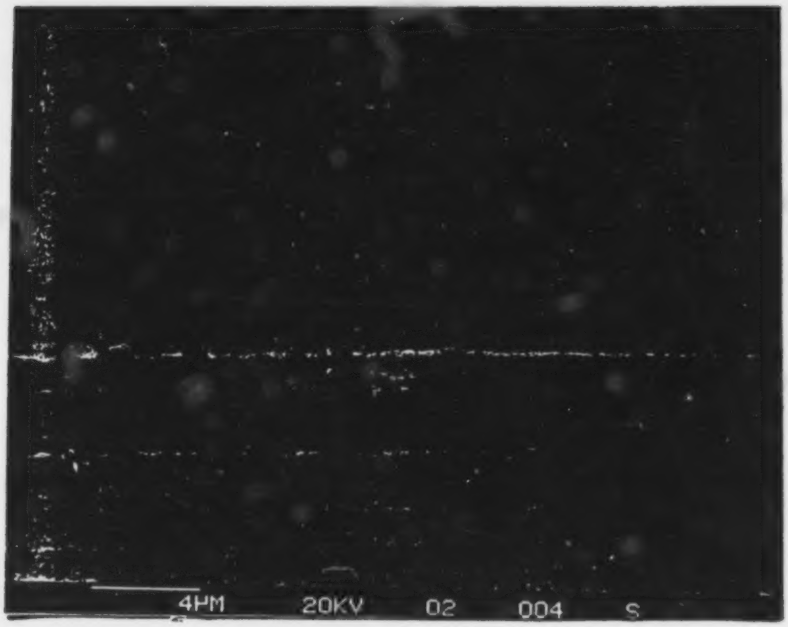

4PM
20KV
02
004
S

FIGURE 4.

#2 CORROSION BAND

However, both of these plungers are corroded to a far lesser degree than those previously examined.

Conclusions:

De-watering the tall-oil fuel has a beneficial effect on the pitting corrosion rate of the fuel injection plungers.

Yours very truly,
HANSON MATERIALS ENGINEERING LTD.

Ian D. Peggs, Ph.D., P.Eng.

IDP/dmn
Met. Tech. Tal Pizzey
E85-7-1078

DR. IAN D. PEGGS

PERMIT TO PRACTICE
Hanson Materials Engineering (Alberta) Limited
Practicing Under Hanson Materials Engineering
Signature
Date 20 Aug 86
PERMIT NUMBER: P 4144
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

APPENDIX V

ENGINE TEST RESULTS (TALL OIL FATTY ACIDS)

A long term engine test was performed at the University of Saskatchewan to assess the effects of the tall oil fatty acid fuel on engine performance and endurance.

Testing was performed on a Deutz model F2L 912 direct injection aircooled diesel engine.

The following report summarizes the results of this test. Included with the report is a post trial inspection by Hansen Materials Engineering (Western) Limited of the fuel pump plungers, fuel injectors and of a bearing. The report is in sub appendix E.

Report and Test Results from Using
Fatty Acids
blended with Diesel Fuel in a
Deutz F2L912 Aircooled Diesel Engine

Prepared for

Prince Albert Pulp Company Ltd.

Box 3001

Prince Albert, Saskatchewan

S6V 5T5

by

W.B. Reed, P.Eng.

and

Perry Schmidt, Research Engineer

Department of Agricultural Engineering
University of Saskatchewan
Saskatoon, Saskatchewan
S7N 0W0

January 1986

Contents

Page

Introduction 1
Scope of Test 1
Results and Discussion 2
  Specific Fuel Consumption 2
  Maximum Engine Power 3
  General Engine Performance 3
  Crankcase Oil Consumption 3
  Crankcase Oil Analysis 4
  Engine Compression Readings 5
  Engine Deposits 6
  Engine Wear 7
  Diesel Fuel System 8

Summary and Conclusions 8
Figure Ia - Instrumentation 10
Figure Ib - Crankcase Oil Consumption 10
Photographs - Figures 2 to 51 11
Appendix A - Specific Fuel Consumption vs Engine Power 36
Appendix B - Engine Power vs Engine Speed 50
Appendix C - Lubriscan Crankcase Oil Analysis 64
Appendix D - Engine Wear Measurements 97
Appendix E - Report from Hanson Materials Engineering 100

Introduction

This report is subsequent to the earlier reports of February 1984, January 1985 and June 1985 entitled "Report and Test Results from Using Crude Tall Oil Blends as a Fuel in a Diesel Engine." Prior to the time when the June 1985 report was issued the Deutz engine was rebuilt and reinstalled to drive the Froude dynamometer. The instrumentation and procedures for fuel consumption and power measurement during the tests documented in this report were as for the previous report. Fuel preparation procedure differed for the Fatty acid/Diesel blends than from the tall oil/diesel blends.

Scope of Test

The period of engine operation reported on within this report, include 100 engine hours with 100% Premium Diesel fuel as an engine break-in period and 1570 engine hours with 50/50:Fatty acids/Diesel fuel.

Note that, engine hours mentioned in this report referring specifically to hours use with fatty acids do not include the 100 hours break-in period. Total time of engine operation was 1670 hours.

During the test period, 125 mL oil samples from the Deutz engine crankcase were taken every 20 hours for analysis of metal and other elemental content. Crankcase oil used during the test was Co-op DMO SAE-30 oil. The samples were analyzed with a plasma-arc spectrometer at the Federated Co-operative Oil Refinery laboratory in Regina. The crankcase oil was drained and replaced after every 60 hours of operation, except between 1400 and 1570 engine hours, when the intervals were 80 and 90 hours respectively.

The Deutz engine was operated at a speed of 2000 rpm with a load of approximately 70% of maximum power. Fuel consumption and power output of the engine were measured. A record of crankcase oil consumption was kept, along with any servicing of the engine or fuel system. The instrumentation and equipment used in the tests is shown in the schematic of Figure 1.

At the end of the test the engine was completely disassembled, all parts inspected and measurements made to determine the amount of wear. Photographs of many parts were obtained and are included in this report.

Fuels

The fuels used and the preparation of the fuels is as follows:

(a) Diesel Fuel: Co-op Red Premium Summer Grade Diesel Fuel was used during the entire test. This included an 100 hour break-in period using 100% Diesel fuel, followed by 1570 hours of 50:50 Fatty acid/Diesel blend.

(b) Fatty Acids: The trademark of the Fatty acids used was Pamak C-4. These Fatty acids are manufactured and supplied by the Hercules Canada Inc. Company of Burlington, Ontario.

(c) Preparation: The blended fuels consisted of mixing equal quantities of Diesel Fuel and Fatty acids. The mixture blended readily at room teperatures with a minimum of agitation. None of the mixture was wasted since no precipitates were present.

(d) Filtering: Although the blend was homogenous a transfer pump and a series of filters were used to filter the fuel mixture before using in the engine. Three filters were used in series for the filtering process. These were a 75 micron Gresen metal screen, a 30 micron Fram filter No. P1146 and a 10 micron Fram filter No. 1653.

In addition to the pre-filtering procedure, the fuel was filtered during engine operation. The primary fuel filter was a Fram PH8A (10 micron) and the final fuel filter was a Fram P4102 (5-10 micron). A vacuum gauge installed at the outlet of the primary filter and a pressure gauge at the outlet of the final fuel filter indicated filter condition while the engine was operated.

RESULTS AND DISCUSSION

Specific Fuel Consumption

Measurements of fuel consumption were made periodically. The specific fuel consumption at or near 18 kW is given in Table 1 below.

Table 1. Specific Fuel Consumption

Engine Hours	Fuel	Engine Speed rpm	Power KW	SPFC g/kWh
0.5	Diesel	2000	18	222
18	FA/DSL	2000	18	237
110	FA/DSL	2000	18	241
245	FA/DSL	2000	18	245
478	DIESEL	2000	18	223
498	FA/DSL	2000	18	246
534	FA/DSL	2000	18	241
861	FA/DSL	2000	18	250
1001	FA/DSL	2000	18	245
1208	FA/DSL	2000	18	241
1361	FA/DSL	2000	18	243
1373	FA/DSL	2000	18	244
1565	FA/DSL	2000	18	240

* Note: - Fuel injection timing 32^{o}BTDC
- FA/DSL - Fatty acids; mixed with equal volume of Diesel
- SPFC vs Brake Power Curves are found in Appendix A.

The specific fuel consumption was lower with Diesel fuel than with 50/50:FA/Diesel fuel mixture. The average SPFC with Diesel fuel remained constant at 223 g/kWh at 18.0 kW power level and an engine speed of 2000 rpm. With the FA/Diesel mixture the SPFC was 237-250 g/kWh at 18.0 kW power level and an engine speed of 2000 rpm. This difference amounts to 11% more fuel consumption when using the FA/Diesel mixture. The range of SPFC is due to changes in engine condition and in particular due to fuel injection nozzle condition.

Maximum Engine Power

The table of maximum power and fuel consumption cannot always be compared directly from trial to trial because of changes in engine condition, particularly the condition of the fuel injector nozzles. The use of FA had an adverse effect on the fuel injector nozzles due to the carbon build-up on the nozzle tip. Partially clogged fuel injector nozzles appear to have a greater adverse effect on engine performance when burning FA blends than when burning Diesel fuel alone. This may be due in part to the higher viscosity property of the FA/Diesel blend which may result in a poor dispersion of the fuel from the nozzle. The maximum power output with various fuels is given in Table 2 and Appendix B. Further details of fuel injector nozzle performance is found under the discussion of the Diesel pump performance.

Table 2

Maximum Power Output of Power Tests

Engine Hours		Engine Speed rpm	Max Power kW	SPFC g/kWh
2	Diesel	2100	24.0	240
20	FA/Diesel	2110	24.2	253
112	FA/Diesel	2110	24.3	254
247	FA/Diesel	2100	23.0	256
481	Diesel	2100	24.4	249
500	FA/Diesel	2110	22.6	267
536	FA/Diesel	2100	23.3	265
864	FA/Diesel	2120	23.8	268
1003	FA/Diesel	2100	25.4	256
1210	FA/Diesel	2120	25.7	255
1363	FA/Diesel	2105	25.0	261
1365	FA/Diesel	2115	26.1	257
1568	FA/Diesel	2105	25.4	258

General Engine Performance

Overall performance of the engine during the trial was good. Test duration was from May to October. Cold weather, below 0°C, was not encountered, thus, cold starting expectations are unknown. However, at near 0°C temperatures, starting was very good - comparable to starting with 100% Diesel fuel.

Crankcase oil Consumption

One problem encountered, which was not fuel related but is occassionally a difficulty with engines, was that the piston rings did not seat properly. The result was, that from initial start-up with Diesel fuel until 420 hours of operations on FA/DSL, a total of 520 engine hours, the oil consumption was excessive and slowly increased to 1.8% of fuel consumed. Table 3 and Figure 1b gives the oil consumption expressed as a percentage of fuel consumption.

Table 3 Engine Oil Consumption

Engine Hours	Oil Consumption Percent of fuel consumed	Engine Hours	Oil Consumption Percent of fuel consumed
End of breakin period	1.3	700	0.2
120	1.5	760	0.1
180	1.4	880	0.1
240	1.5	940	0.1
300	1.5	1000	0.1
360	1.7	1080	0.1
420	1.8	1140	0.1
		1260	0.1
Rings, Pistons & Cylinders replaced			
460	0.4	1320	0.1
520	0.4	1380	0.1
580	0.3	1480	0.1
640	0.2	1570	0.2

After the 520 hours the heads, cylinders and pistons were removed. The piston rings still retained their original shiny lustre with virtually no wear showing on the cylinders, pistons or piston rings. The high oil consumption rate was attributed to oil leakage past the piston rings. This was evident by a ring of carbon deposited on the top of both pistons adjacent to the circumferential edge; the evidence of burnt crankcase oil. Photographs in Figures 2, 3, 6 and 7 clearly show these deposits. The intake valves had heavy deposits on the tulip portion of the valve stem as shown in Figure 11. Other photographs in Figure 4,5, 8, 9 and 10 show condition of cylinders, pistons and exhaust valves.

Crankcase Oil Analysis:

Samples were withdrawn from the crankcase oil sump at 20 hour intervals. The concentration of the following elements within the oil was obtained by a Lubriscan analysis provided by the Federated Co-Operative Oil Refinery laboratory in Regina, Sask.

Iron
Chromium
Aluminum
Copper
Lead
Tin
Silicon
Sodium

Boron
Magnesium
Calcium
Barium
Phosphorous
Zinc
Sulfur
Oil Viscosity

Note that the scanning for Nickel and Silver was also done but the levels were always zero.

The concentrations reported in parts per million are plotted versus engine hours for the total engine operating period of 1670 hours. The graphs are found in Appendix C.

Viscosity: The crankcase oil viscosity normally tended to increase about 0.5 CST during a 60 hour period. Extending the oil change period from 60 hours to 80 and 90 hours near the end of the test caused a sharp increase in viscosity from about 12 CST to over 14 CST. A complete graphical plot of the viscosities is found in Appendix C.

Iron: The concentration of iron never approached the allowable limit of 90 ppm. Slight increases may be noted at 540, 1080, 1580 and 1670 hours. The engine cylinders, pistons and rings were changed at 520 hours, a fuel injector failed at 1080 hours and engine oil change periods were extended near the end of the test at 1580 and 1670 hours. These events evidently contributed to the increase in iron and other materials.

Chromium: Values for chromium concentration were variable but were higher during the latter half of the test period.

Aluminum: The concentration increased to the allowable limit twice during the test and exceeded the limit at the time of the fuel injector failure at 1080 hours. Operation with partially failed fuel injectors at other times may account for some of the other higher values.

Copper: A point of high concentration (26 ppm) occurred at the time of the failed injector of 1080 hours. High concentrations occurred again near the end of the test period, where the allowable levels (30 ppm) were exceeded, and coincided with the longer oil drain intervals.

Lead: The level of lead was excessive following the failed fuel injector nozzle at 1080 hours and was higher than the allowable limit at the end of each crankcase oil drain interval for the remainder of the test. Very high concentrations of lead occurred near the end of the test where the oil drain intervals were extended. The evident pitting of the connecting rod bearings, caused by corrosion, was responsible for these high levels.

Tin: The concentration of tin generally remained well below the allowable limits.

The values of the concentrations of the other elements, including silicon, sodium, boron, magnesium, calcium, barium, phosphorous, zinc and sulfur were recorded and are given in the Appendix. These elements and their concentrations reveal the type of additives in the particular crankcase oil, although silicon can be an indicator of dirt entering the engine.

These results indicate that poor combustion caused by faulty or fouled fuel injectors contributed to high engine wear rates. It is also apparent that the crankcase oil change interval should not exceed 60 hours when operating the engine under the conditions of the test.

Engine Compression Readings

The reading of engine compression taken several times during the test period are shown in Table 4. Throughout the test the readings varied slightly but were well within or higher than the manufacturers specified range of values (20-28 bars).

Although crankcase oil consumption was excessive during the first 420 hours of operation, the compression readings, power output and fuel consumption were normal. At the end of the test, the No. 2 piston was slightly scuffed but had little or no effect on the compression reading, with the reading on No. 1 cylinder lower than that of No. 2 cylinder. Maximum power readings increased slightly during the latter part of the test.

Table 4 Engine Compression Readings

Engine Hours	Compression Pressure Bars		
	No. 1	No. 2	
21	28	29	engine hot
180	28.3	29	engine hot
252	27.3	29	engine hot
252	27.0	28.7	engine cold
420	28.0	29.5	engine hot
420	Rings, pistons and cylinders replaced.		
982	30.8	28.3	No. 1 fuel injector failed
1000	30.2	29.0	engine hot
1000	29.0	28.8	engine cold
1366	26.5	27.0	engine hot, shut down to service fuel injectors.
1372	29.7	28.8	engine hot
1570	28.7	29.8	engine hot, end of test
1570	27.0	29.0	engine cold, end of test.

Engine Deposits

Cylinder Head and Valves: As mentioned above under Crankcase Oil Consumption the top end of the engine was dismantled at 420 hours to replace cylinders, pistons and rings. The engine had to be stopped once more at 982 hours because one fuel injector had failed. Other servicing of fuel injectors occurred at 180 and 1366 hours.

The deposits on the cylinder heads at 420 hours may be seen in the photographs of Figures 2 and 6. There was a significant amount of deposit on the cylinder heads and the valve heads which was attributed to excessive oil consumption.

At the end of the test (1570 hours) the deposits on the cylinder heads shown in Figures 12, 15 and 16 were less than at 420 hours. The valve head deposit had the characteristic rusty orange color obtained when using crude tall oil whereas the remainder of the deposits, were black. The enlarged views show the valve deposit to be porous and with a relatively soft structure. (Figures 17 to 19). The deposits on the valve stems are shown in photographs of Figure 20 and 21.

Other important deposits were those shown on the valve springs and valve rocker arm assemblies shown in the photographs of Figures 23 to 25. This sludge like substance was also present on other engine parts, including the cam followers, piston pins and the interior of the engine block, but in much lesser quantities. Figure 44 shows the amount on a cam follower.

Cylinders and Pistons: The photographs of Figures 3, 4, 5, 7, 8, and 9 show the deposits on the piston tops, on the piston and within the cylinders after 420 hoiurs, at the time they were removed due to excessive oil consumption. As discussed under Crankcase Oil Consumption, much of the deposits shown were attributed to high oil consumption.

The deposits at the end of the test after 1150 hours of operation as shown in Figures 13 and 14 were not excessive on the piston tops, nor was there a excessive amount of hard carbon on the cylinder wall above the rings. The deposits though had caused interference, at the top of each piston, with the cylinder wall and resulted in some visible wear and scuffing of the piston surface and may be seen in photographs of Figures 26-29. It is possible that the initial formation and scuffing resulted from the severe fuel injector fouling at 982 hour since the operation of the engine continued for several hours with the faulty fuel injector.

Engine Wear

The dimensions of the engine parts after the 1670 hours of operation are given in Appendix D. The amount of wear is indicated by the comparison to the manufacturer's specifications for the various parts as discussed below.

Cylinder and Pistons: The wear on No. 1 cylinder at the end of the test (1150 hours) was .018 mm and on No. 2 cylinder was .005 mm (Figure 13 and 14). These amounts are well below the wear limit of 0.201 mm. The wear on the piston rings was small. Piston wrist pin clearance increased slightly (Fig. 29 and 40). Operation of the engine with the failed fuel injector nozzle likely contributed to the higher amount of wear on No. 1 cylinder.

Cylinder Head and Valves: There was wear on the valve stems, with both intake valves at the limit value of wear. Valve guide wear was also at the limit value.

Throughout entire test engine compression was above the allowable minimum. Compression readings, hot and cold, were between 25-30 bar whereas the specifications give the desired range of 20-28 bar. There was no evidence of valve leakage, which is supported by the compression results given in Table 4.

Crankshaft and Bearings: The crankshaft journals and bearings were in good condition. The clearances were within the nominal clearances. The condition of these parts can be see in Figures 35 to 39. The crankshaft main bearings did not show much evidence of corrosion or wear.

Connecting Rod Bearings: The connecting rod bearings were extensively corroded as shown in Figures 30 to 33. Pitting of the bearing surface is evident and considerable bearing material was removed along the edges of No. 1 connecting rod bearing.

The report from Hanson Materials Engineering confirmed that corrosion had taken place within the bearing and that material removal was not caused by excessive loads or lubrication failure. The report is found in Appendix E.

Camshaft: The camshaft journals and bearings were in good condition. However, the front bearing showed wear with a clearance of .114 mm or .005". All of the cam lobes were worn with wear ranging from .070 to .085 mm. The surface condition of the journals and lobes was polished and normal in appearance as seen in Figures 41 to 43.

The camshaft followers were pitted, as in previous trials, and would lead to eventual camshaft failure. Figures 44. 45 and 46.

Oil Pump: The oil pump was in good condition. The outlet port showed no evidence of wear as compared to the pumps in previous trials.

Diesel Fuel System

Diesel Fuel Pump and Injection Nozzles: Calibration of the fuel injection pump showed that fuel delivery was within specifications. Plungers and barrels showed minimal wear and were in very good condition. The pump plungers and barrels were removed and examined by Hanson Materials Engineering for wear and corrosion. The report included as Appendix E, reports very little wear and no evidence of corrosion.

The injection nozzles required servicing after 180, 420, 982 and 1366 hours of engine operation, due to carbon buildup. The failures were usually noted by an increase in exhaust gas temperature, a noticeable drop in maximum engine power and an increase in fuel consumption. Severe nozzle wear or corrosion resulted in a hole at the end of nozzle tip at 982 hrs after operating for 562 hours without servicing. Fuel was delivered as a solid stream from the tip. Photographs of the nozzle tips after 205 hours and 562 hours of use are found in Figures 47 to 51.

Summary and Conclusions

The performance of Fatty Acids blended 1:1 with Diesel fuel was good in the Deutz Model F2L912 air-cooled engine in terms of power produced and general engine operation. Engine starting at ambient air temperatures as low as 0°C was equal to starting with Diesel fuel at the same temperatures. Temperature below 0°C were not encountered during the test period.

Specific fuel consumption was 11% higher with the fuel blend than with 100% Diesel fuel. The maximum power output was similar to that obtained with 100% Diesel fuel.

Fuel filter life was not determined, but exceeded 1670 hours, since no restriction of the filters was noted during the entire test period.

The Diesel injection pump performed for the entire test period and the fuel delivery had not changed at the end of the test. An inspection and analysis of the plunger and barrels showed that wear was minimal and no scoring or corrosion had occurred.

The fuel injection nozzles required frequent servicing due to coking on the nozzle tips. The estimated length of operation before servicing the injectors should probably not exceed 350-400 hours. Operating with poor performing injectors appeared to contribute to crankcase oil contamination and increased engine wear. Extended operation of the injectors also caused severe corrosion and eventual failure of the nozzle tip.

Cylinder, piston and ring wear was not excessive, but hard carbon deposits had built up on the piston outer surface above the piston rings. These deposits had not caused serious problems although piston scoring was evident and would eventually result in increased and rapid wear.

The engine valves performed well during the entire test period of 1150 hours and were in good condition at the end of the test. Heavy carbon deposits had accumulated on the tulip portion of the intake valves. A small amount of a soft material, rusty-orange in color, was present on the valve head surfaces in the combustion chambers.

The crankcase and camshaft journals and bearings were in relatively good condition at the end of the test, although the connecting rod bearings corroded a significant amount. Continued operation would have eventually led to bearing failure as the corroded area increased. The camshaft lobes were worn with the face of the cam followers pitted which would result in premature camshaft failure.

The crankcase oil analysis for metal and other elemental content indicated that the oil change period should not exceed 60 hours under the operating condition of the test. Also indicated by the analysis was that poorly performing fuel injectors contributed to increased engine wear.

It is to be noted that none of the wear or evidence of wear had reduced engine performance at the end of the test. Engine compression was high, with power output and specific fuel consumption remaining unchanged, providing the fuel injectors were serviced as necessary.

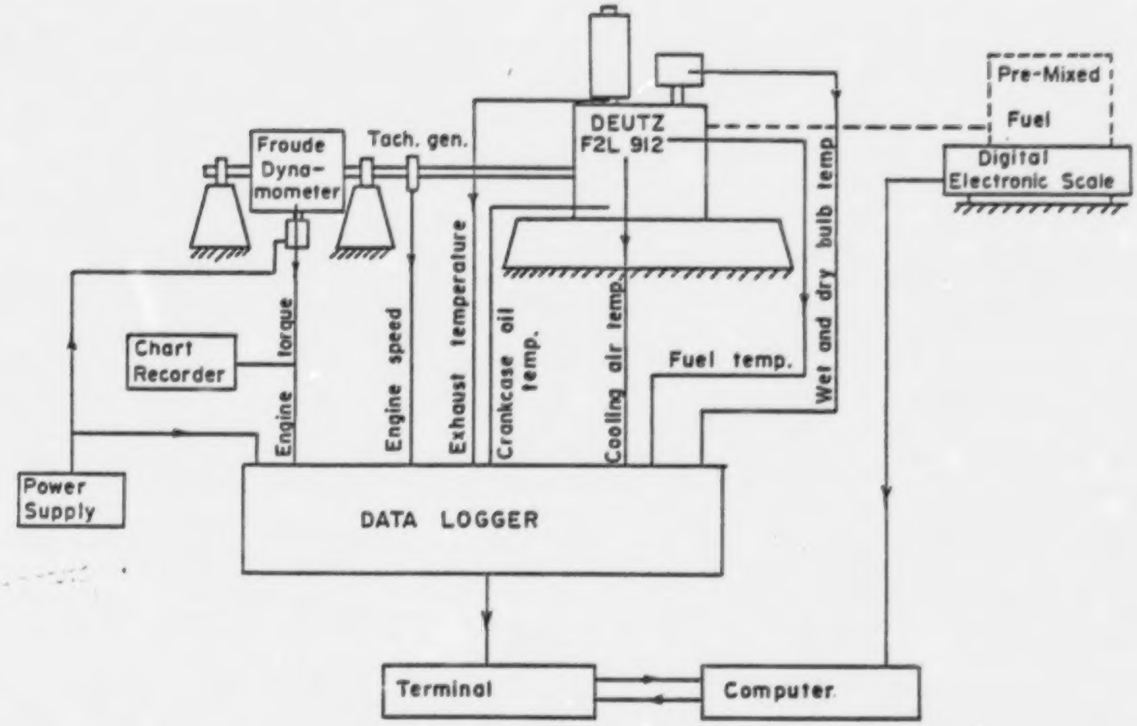

Pre-Mixed
Fuel
DEUTZ
F2L 912
Froude
Dyna-
mometer
Tach. gen.
Digital
Electronic Scale
Chart
Recorder
Engine torque
Engine speed
Exhaust temperature
Crankcase oil
temp.
Cooling air temp.
Fuel temp.
Wet and dry bulb temp
Power
Supply
DATA LOGGER
Terminal
Computer

Figure 1a - INSTRUMENTATION DIAGRAM

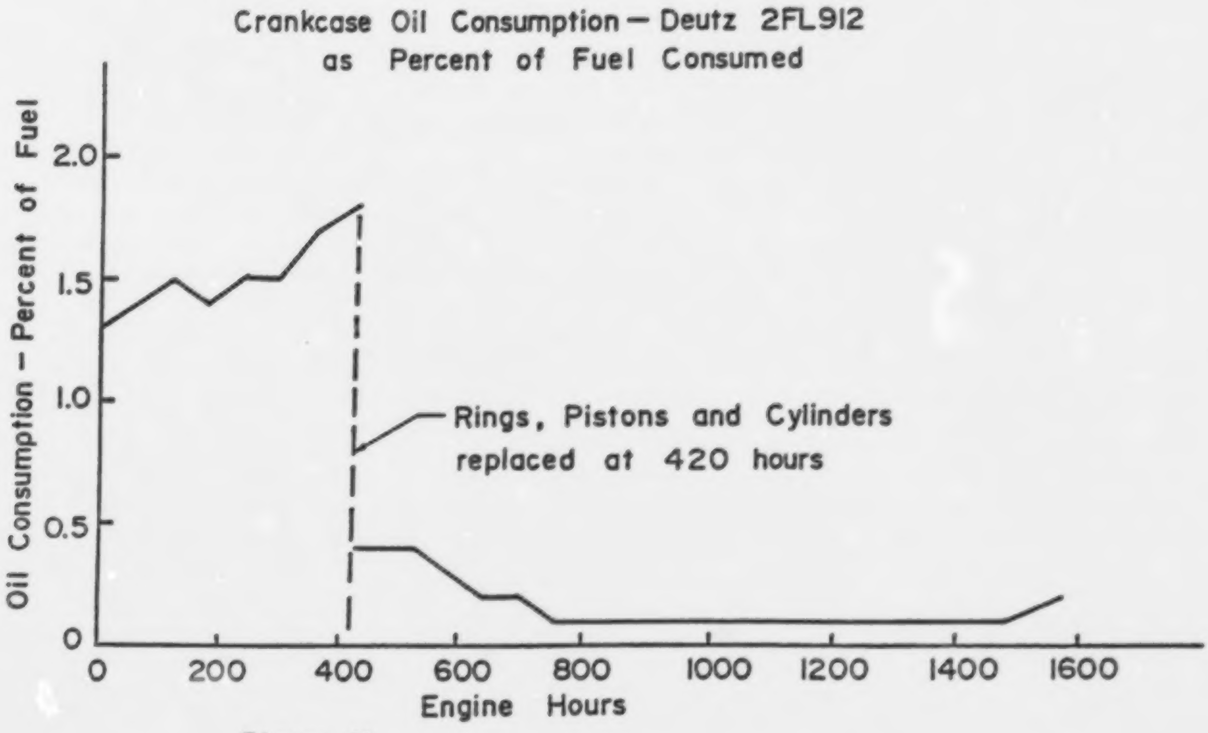


Figure 1b

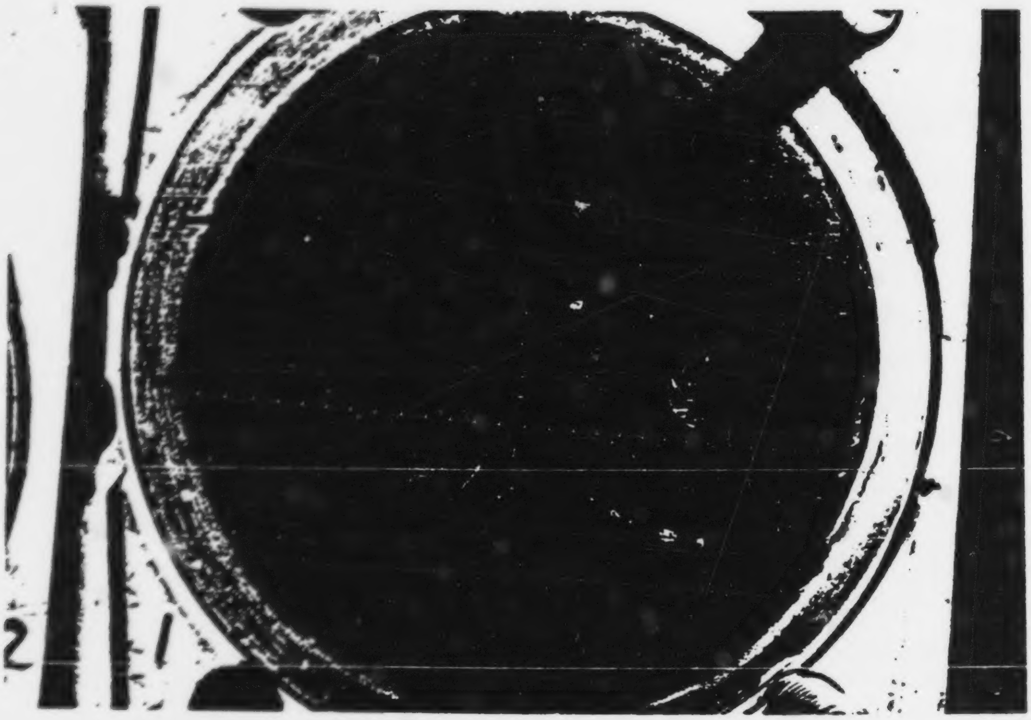


Figure 2. Carbon deposit on No. 1 cylinder head attributed to burning of crankcase oil.

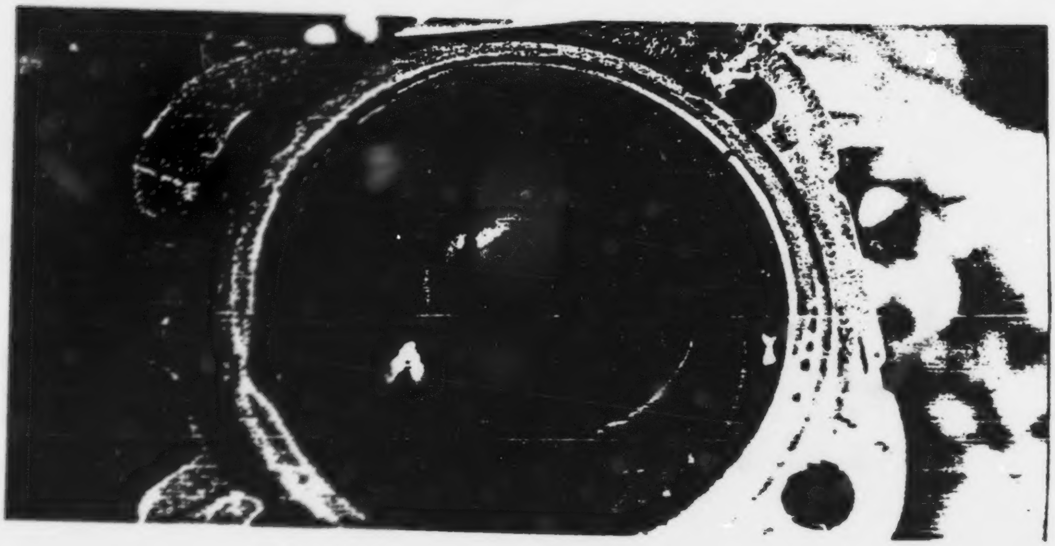


Figure 3. Carbon deposit on No. 1 piston attributed to burning of crankcase oil.

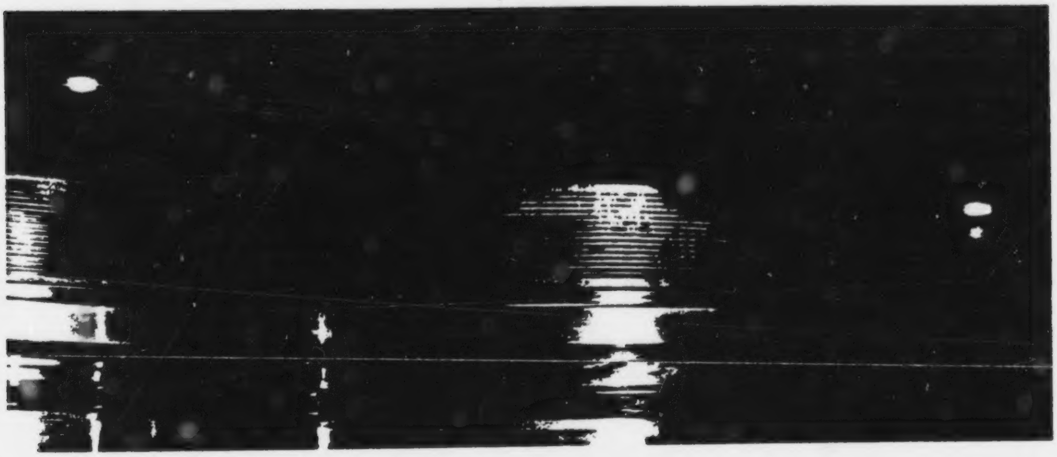


Figure 4. No. 1 Piston side - 420 hours.

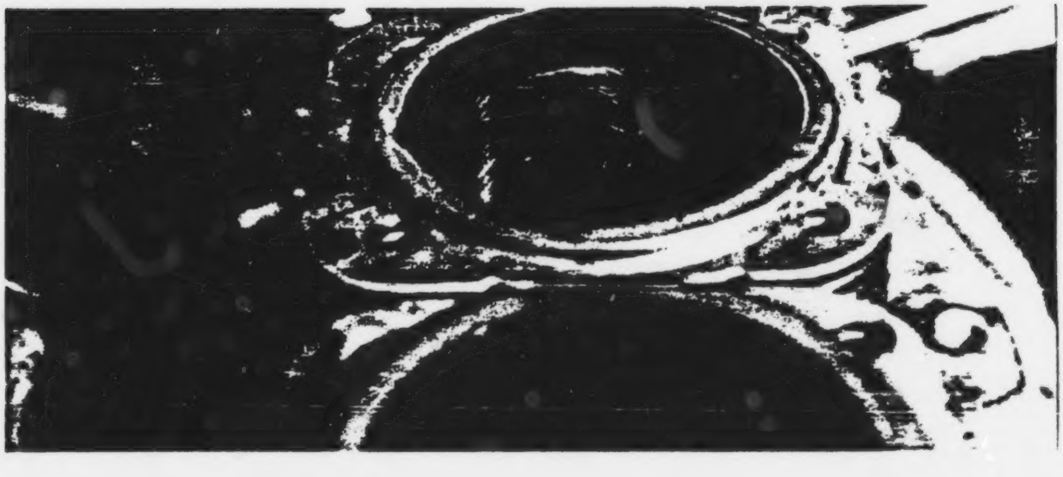


Figure 5. Interior of No. 1 cylinder. Original hone marks visible.

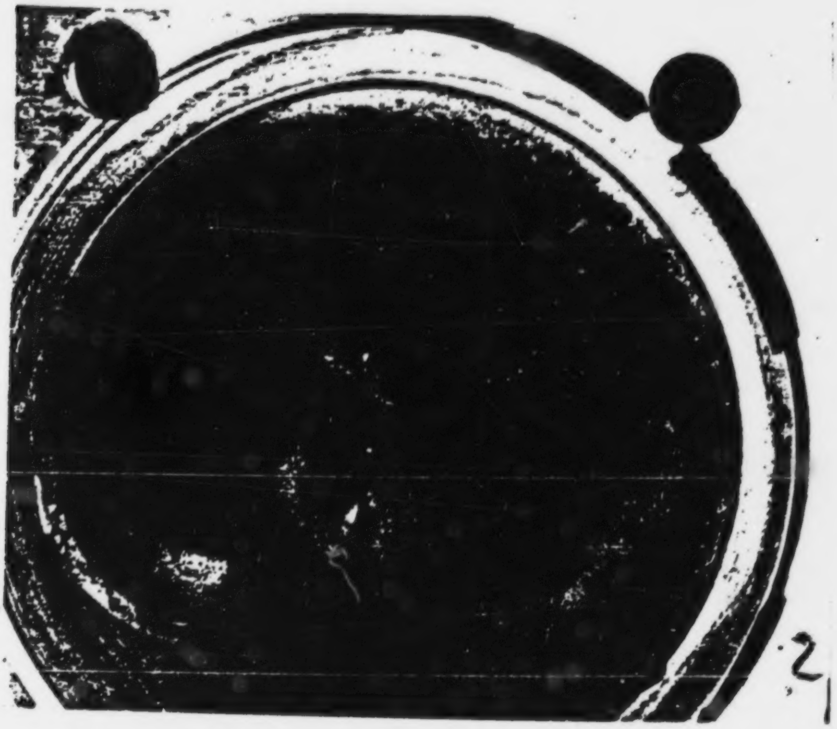


Figure 6. Carbon deposit on No. 2 cylinder head attributed to burning of crankcase oil - 420 hours.

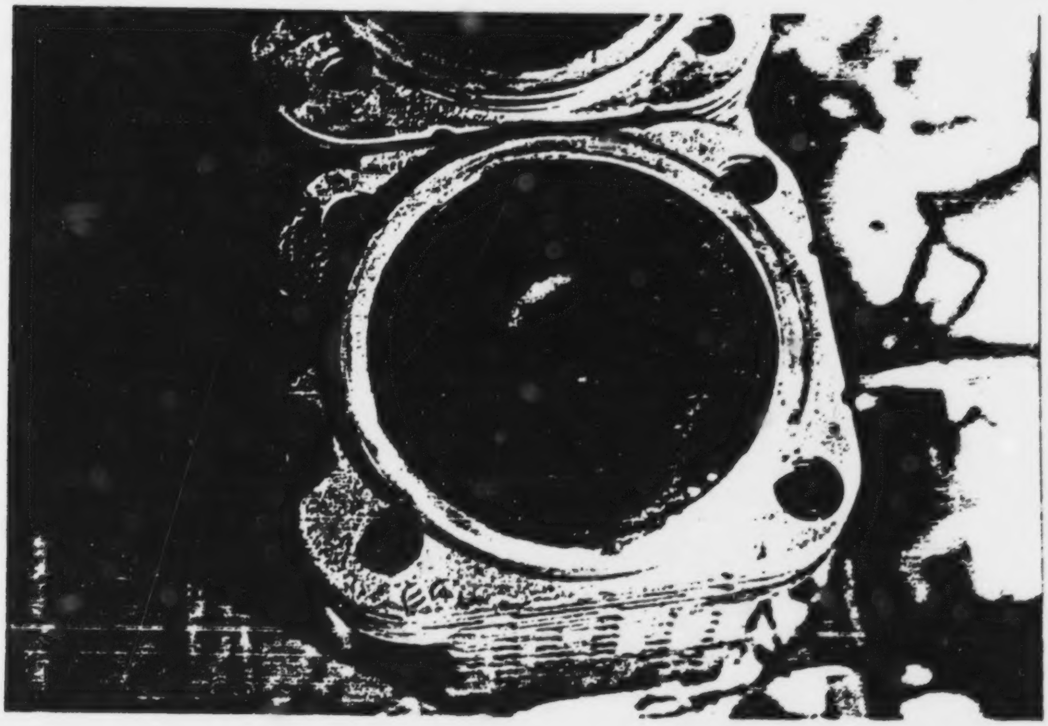


Figure 7. Carbon deposit on No. 2 piston - 420 hours.

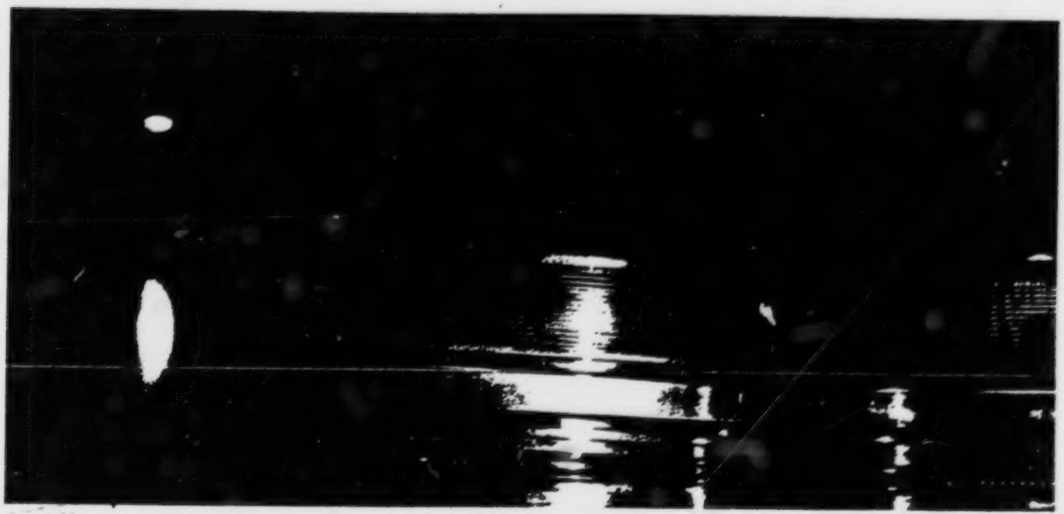


Figure 8. No. 2 Piston side - 420 hours.

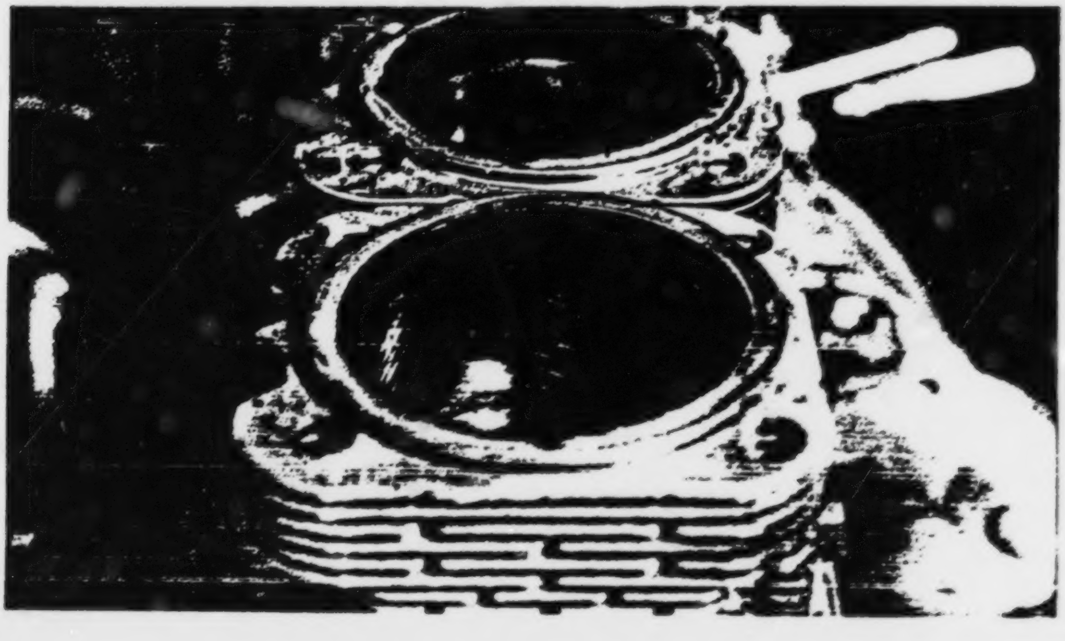


Figure 9. Interior of No. 2 cylinder. Original hone marks visible.

Figure 10. No. 1 and No. 2 Exhaust valves - 420 hours.

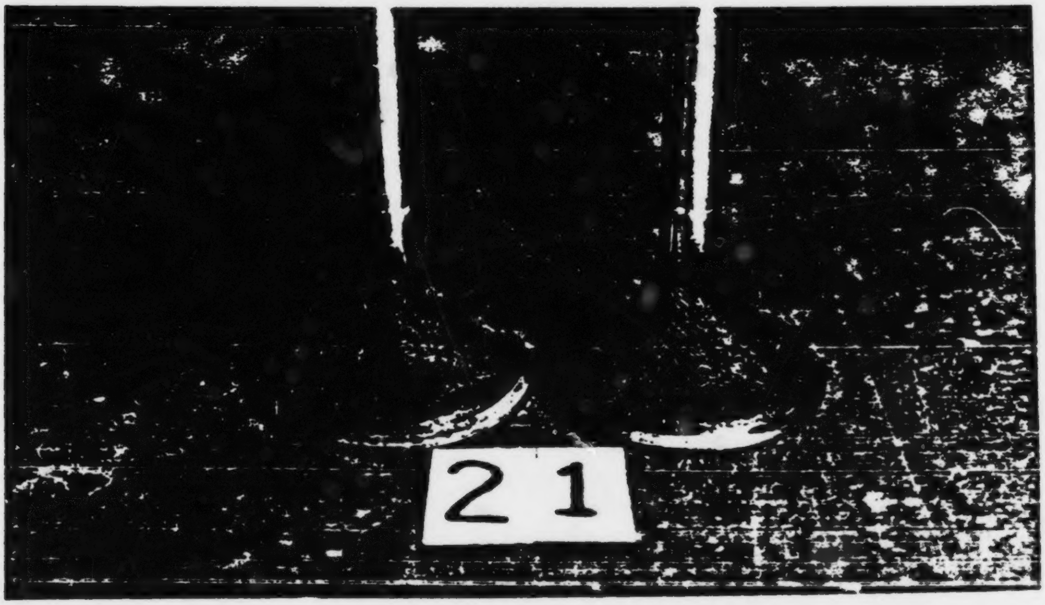


Figure 11. No. 1 and No. 2 Intake valves - heavy deposits present on tulip at 420 hours attributed to burning of crankcase oil.

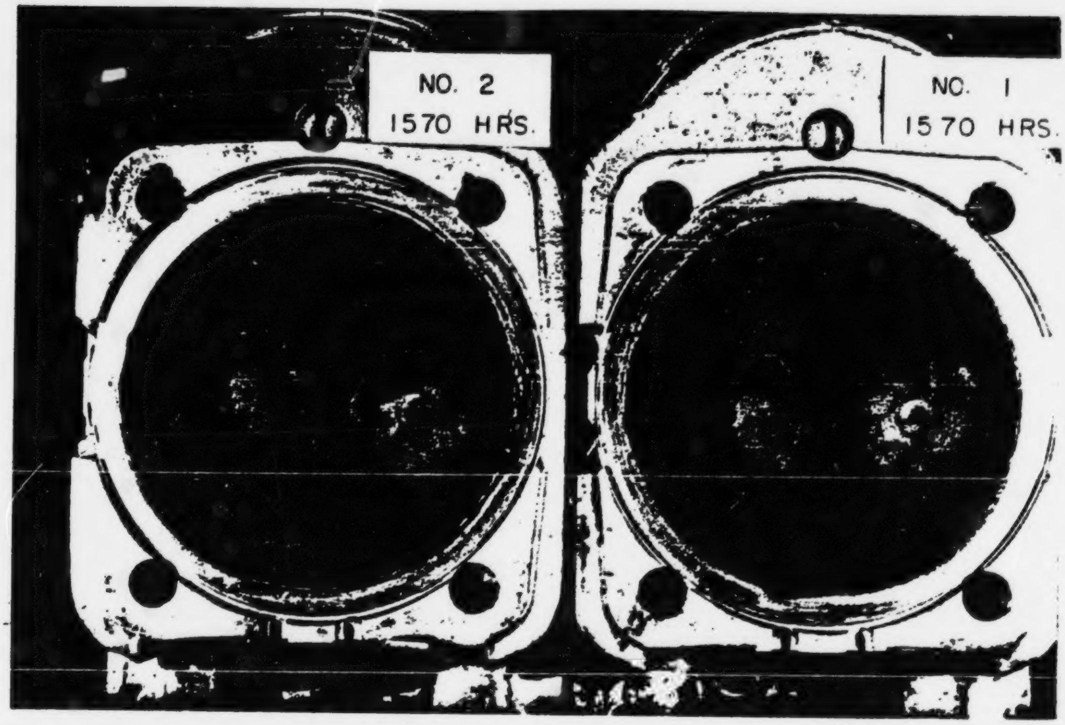

NO. 2
1570 HRS.
NO. 1
1570 HRS.

Figure 12. Cylinder heads after 1570-420 = 1150 hours operating on fatty acids.

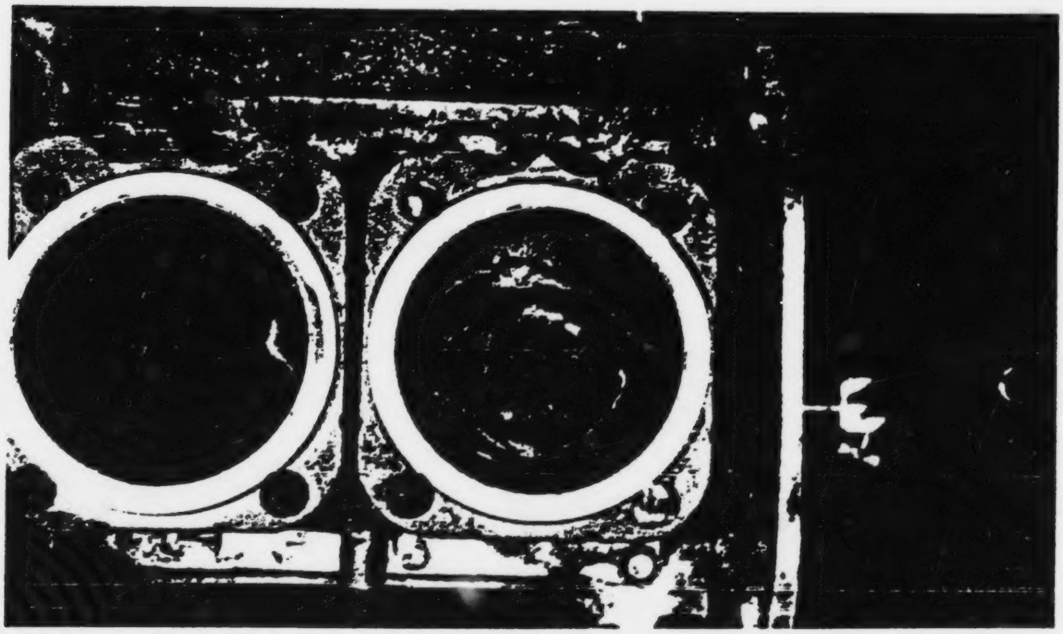


Figure 13. No. 1 Piston top after 1150 hours operation on fatty acids.

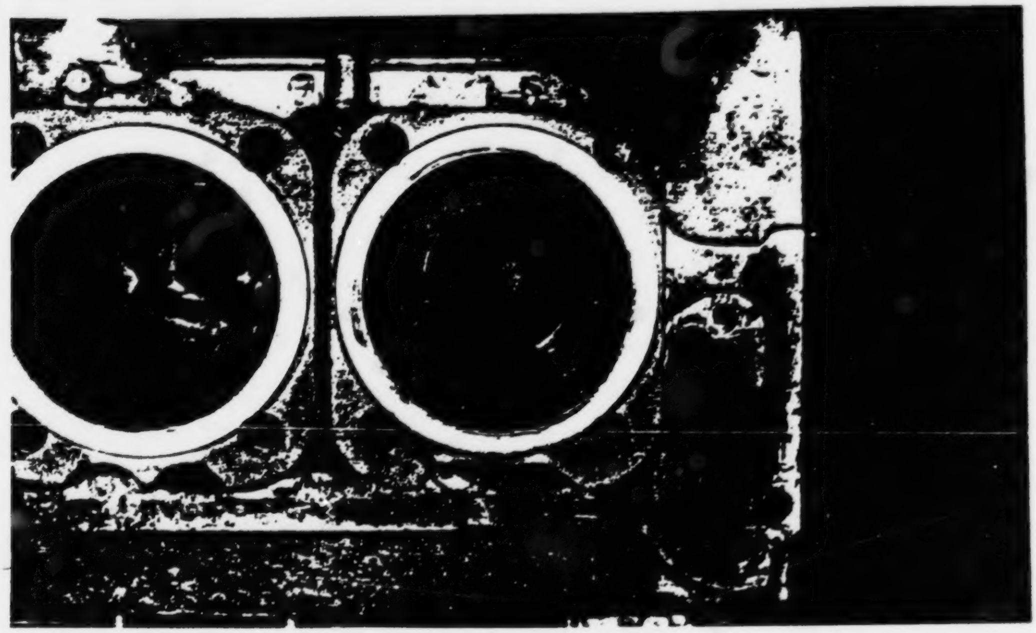


Figure 14. No. 2 Piston top after 1150 hours operation on fatty acids.

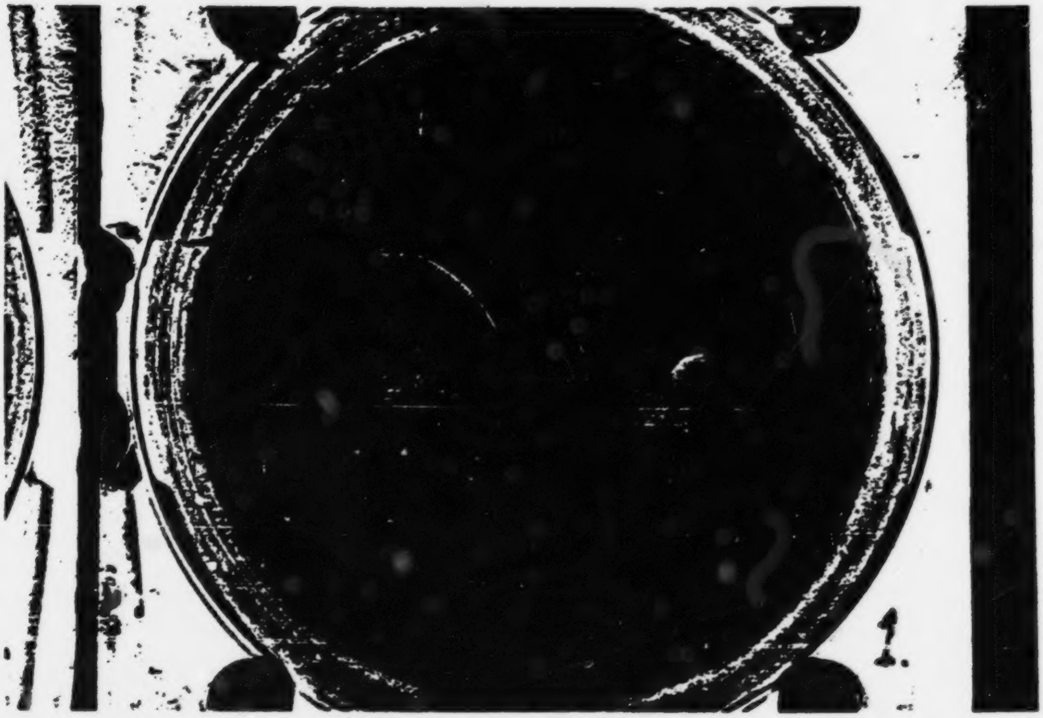


Figure 15. No. 1 Cylinder head deposit after 1150 hours operation on fatty acids.

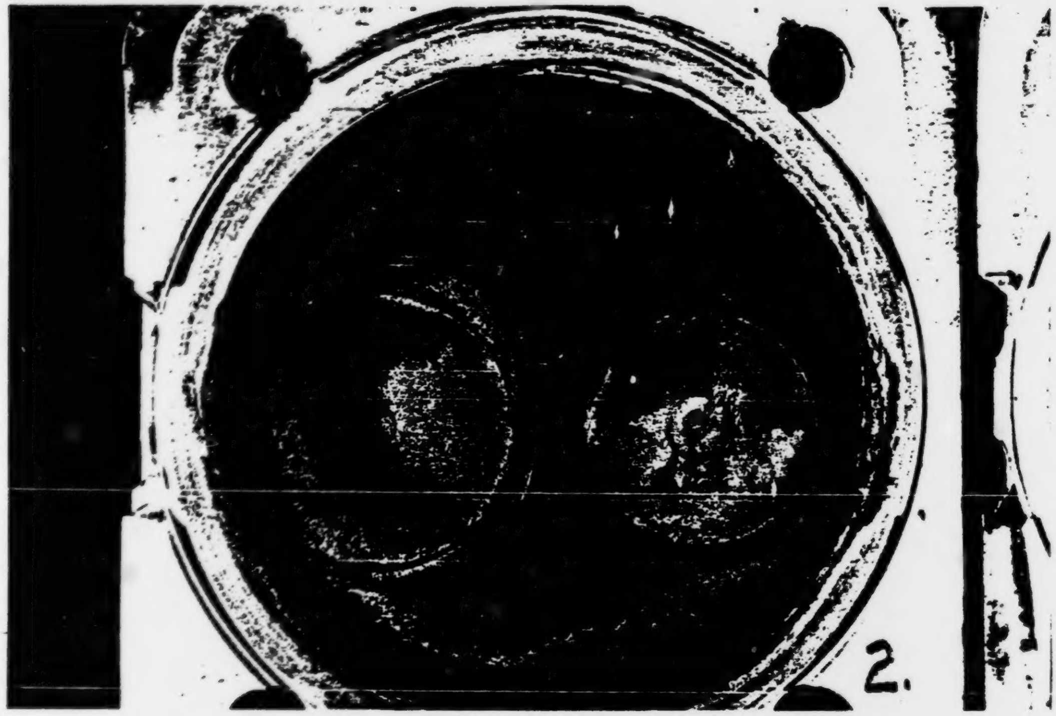


Figure 16. No. 2 Cylinder head deposit after 1150 hours operation on fatty acids.

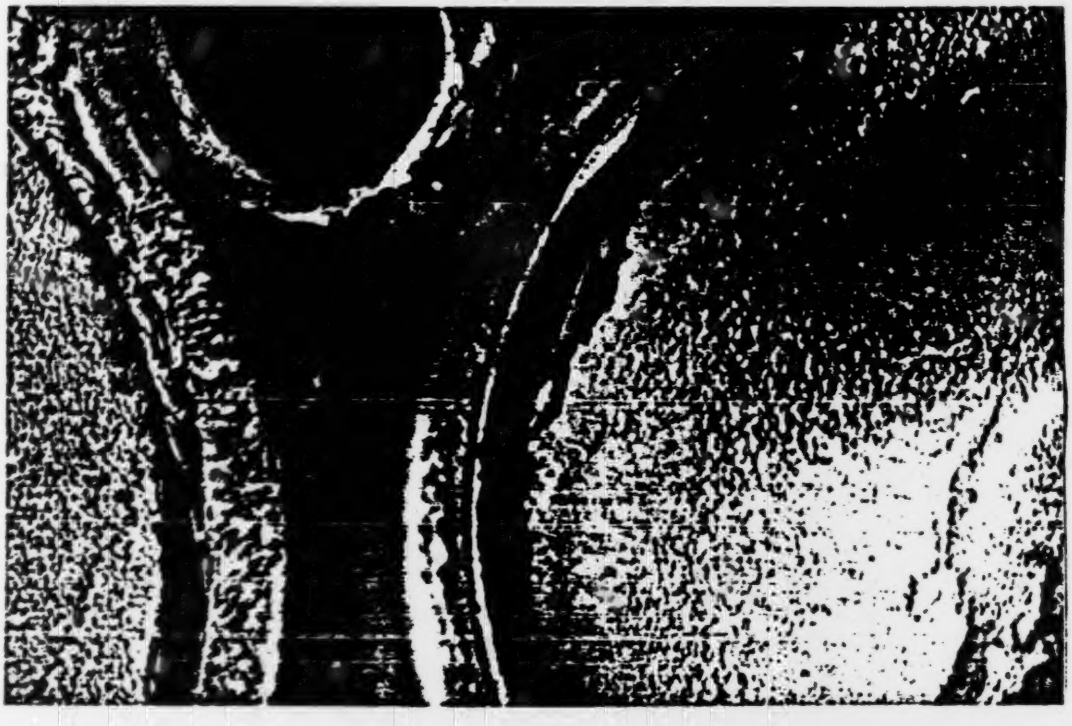


Figure 17. Enlarged view of deposit on No. 2 exhaust valve as shown in Fig. 16.

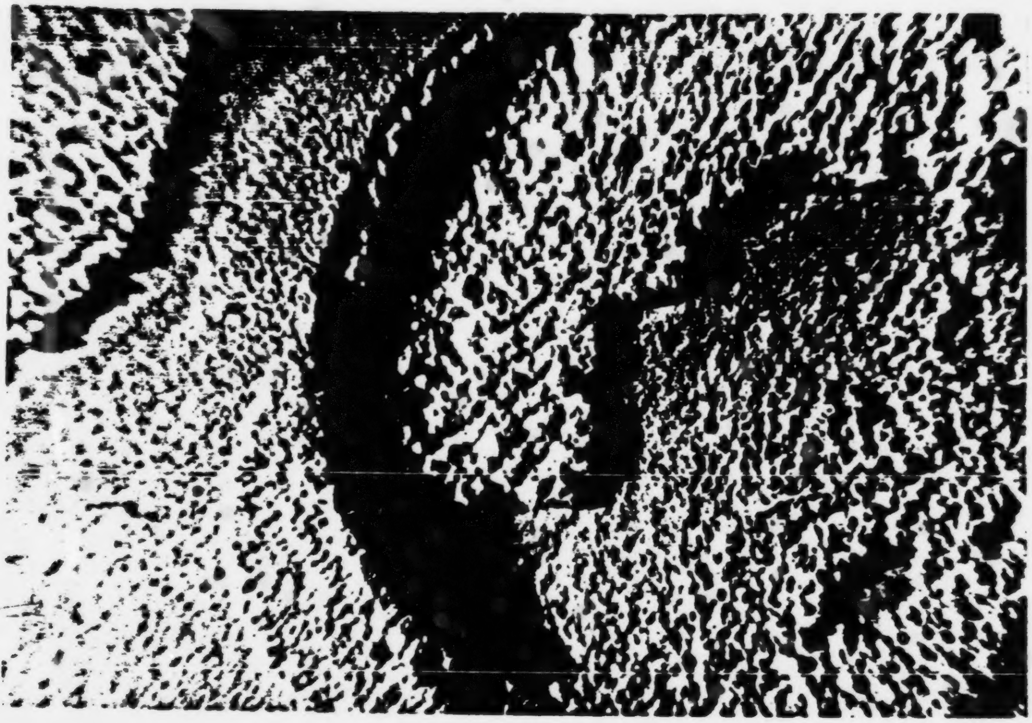


Figure 18. Enlarged view of deposit on No. 1 exhaust valve shown in Fig. 15.

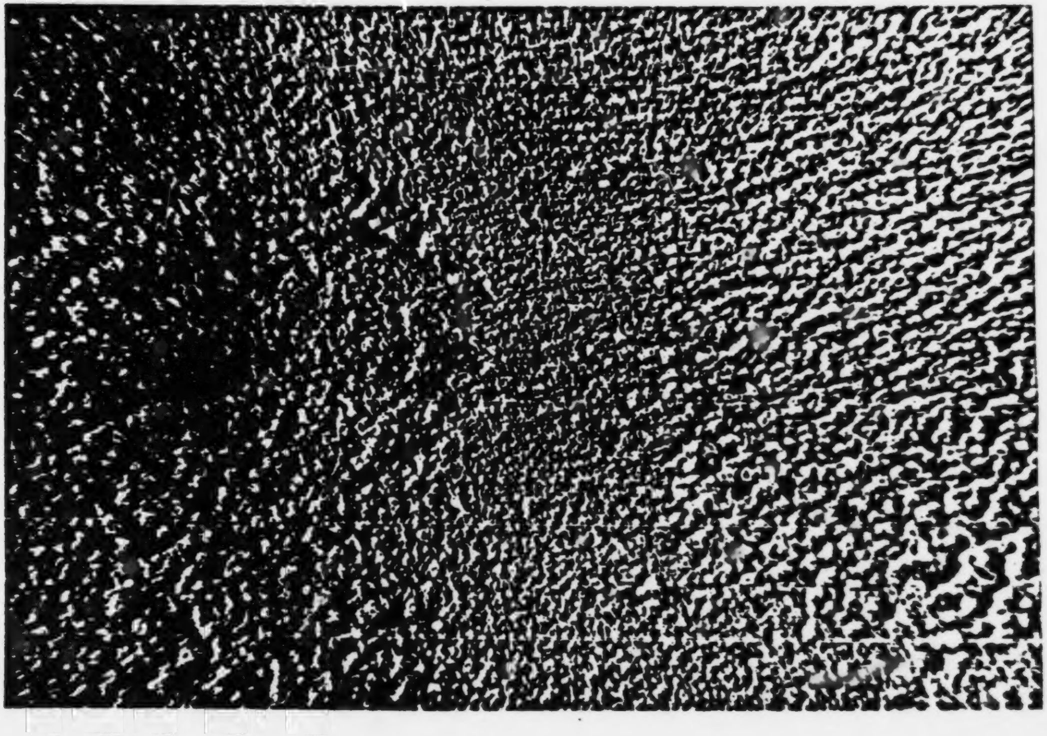


Figure 19. Enlarged view of deposit on No. 1 intake valve shown in Fig. 15.

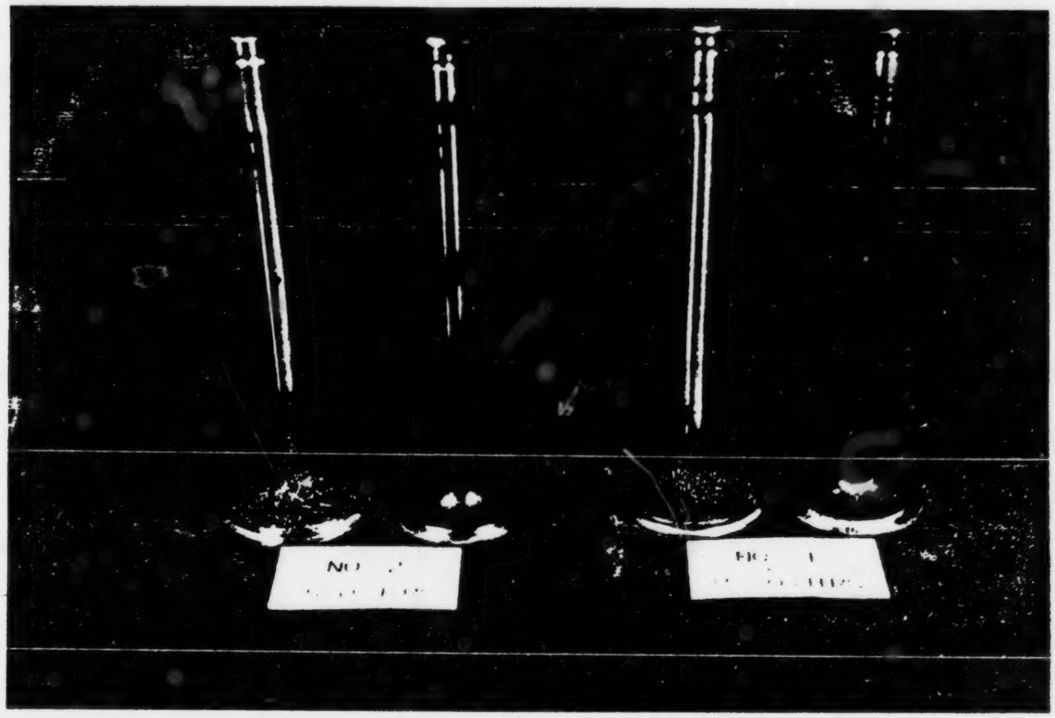


Figure 20. Engine valve after 1150 hours operation on fatty acids.

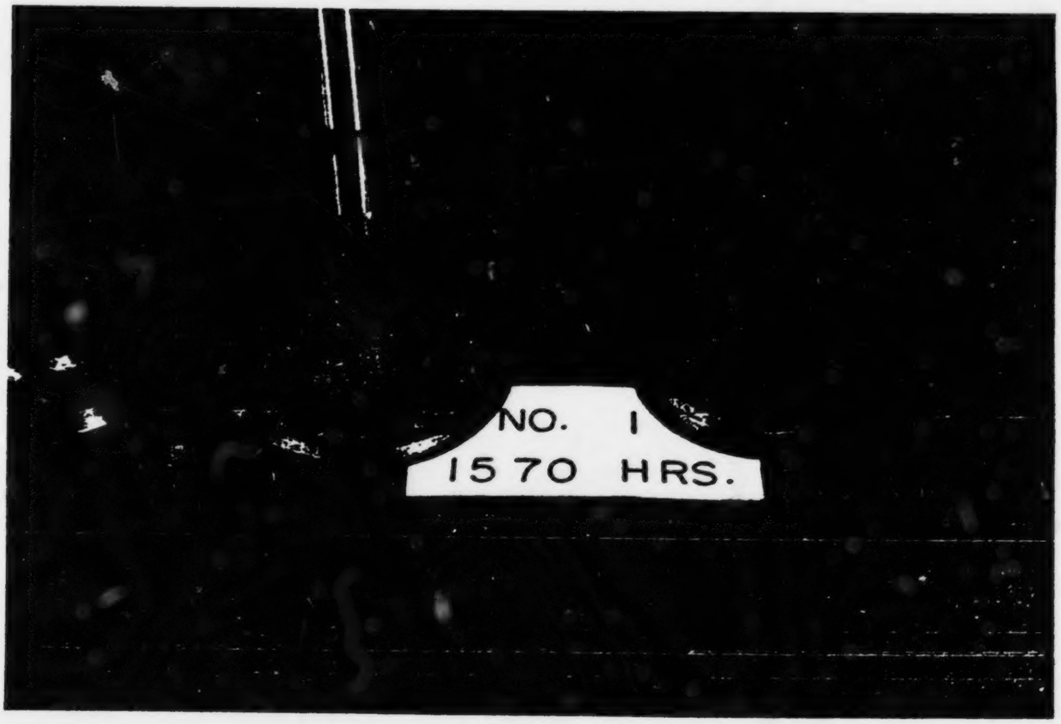


Figure 21. No. 1 cylinder valves after 1150 hours operation on fatty acids.

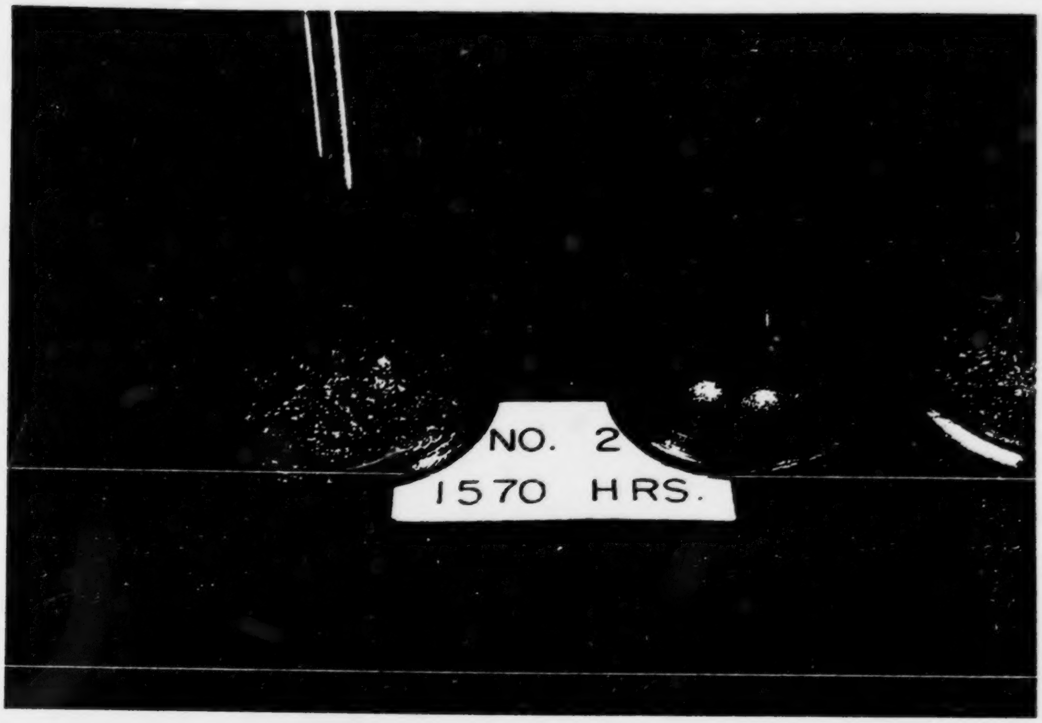


Figure 22. No. 2 cylinder valves after 1150 hours operation on fatty acids.

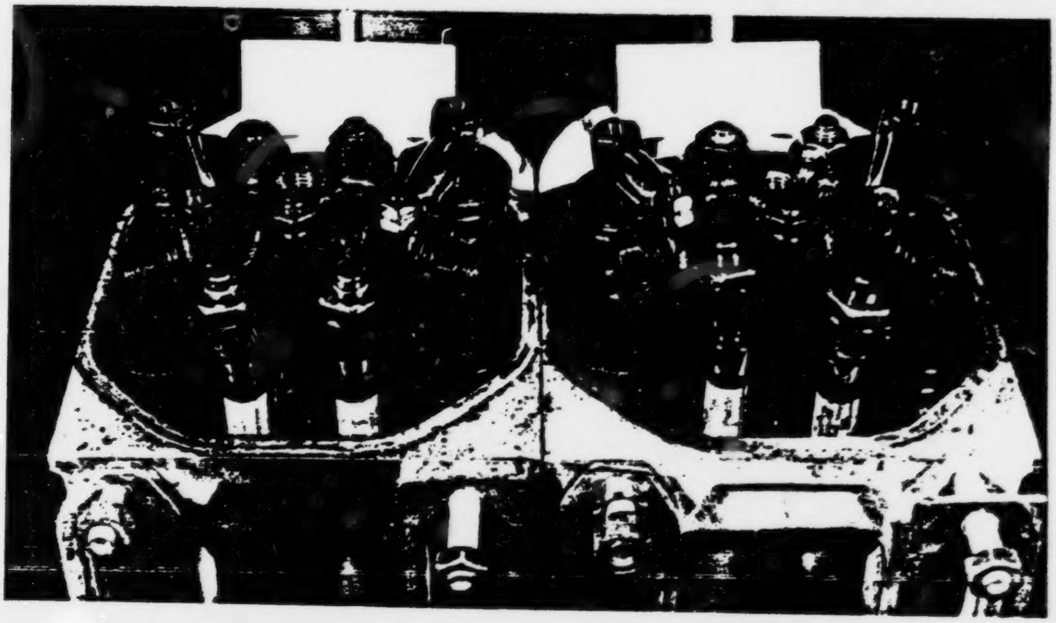


Figure 23. Valve lifter assemblies after 1150 hours operation on fatty acids.

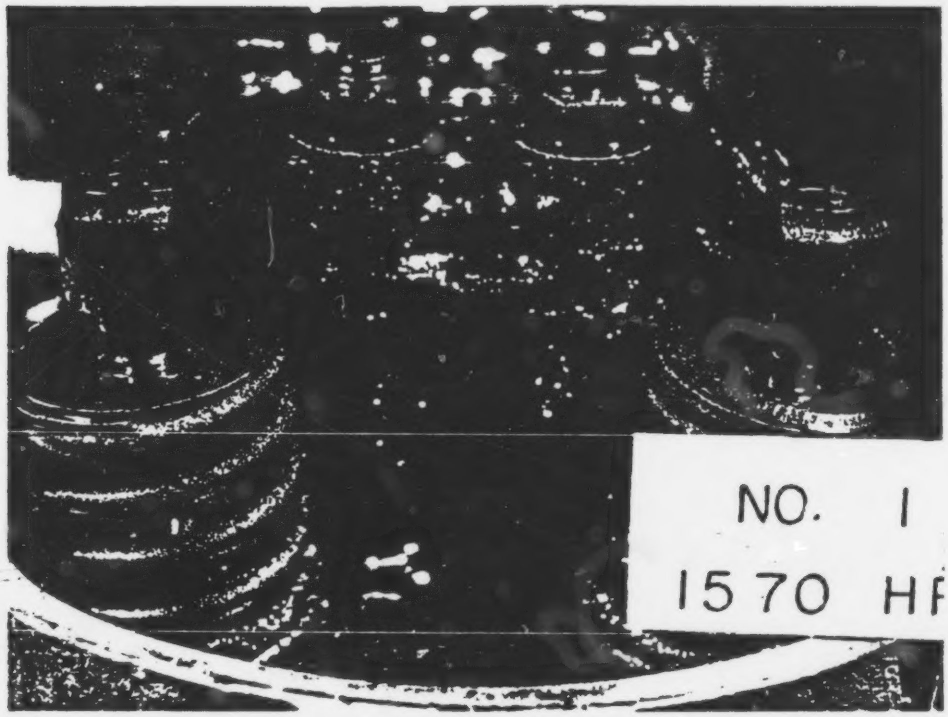


Figure 24. No. 1 cylinder valve lifter assembly after 1150 hours operation on fatty acids. Note deposits on assembly.

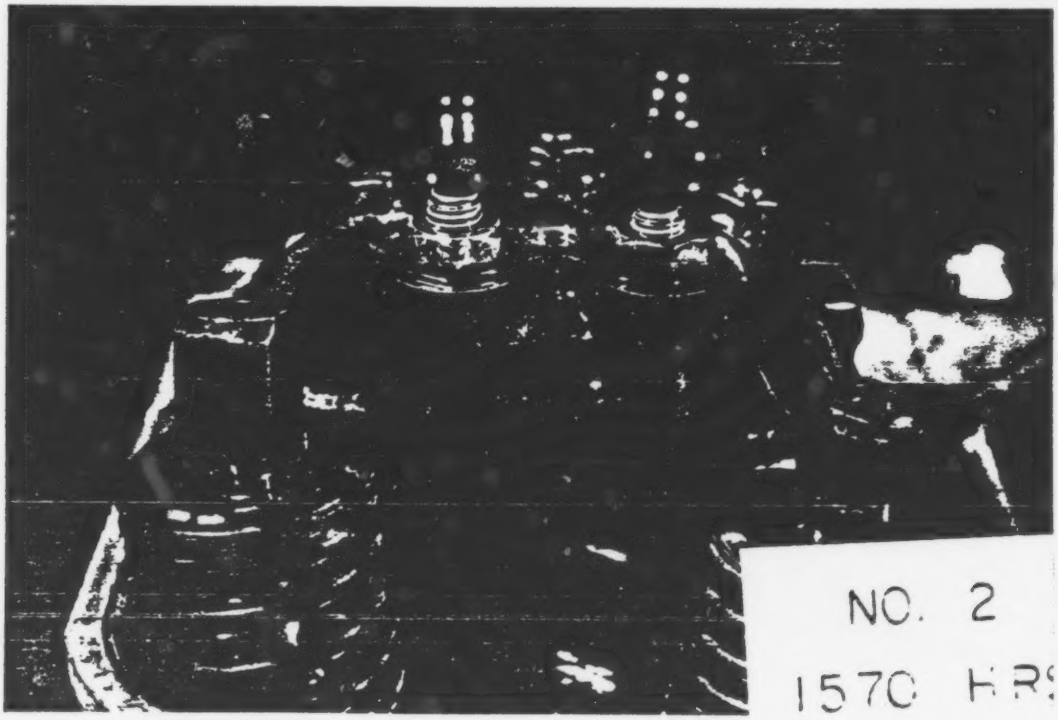

NO. 2
1570 HRS

Figure 25. No. 2 cylinder valve lifter assembly after 1150 hours operation on fatty acids.

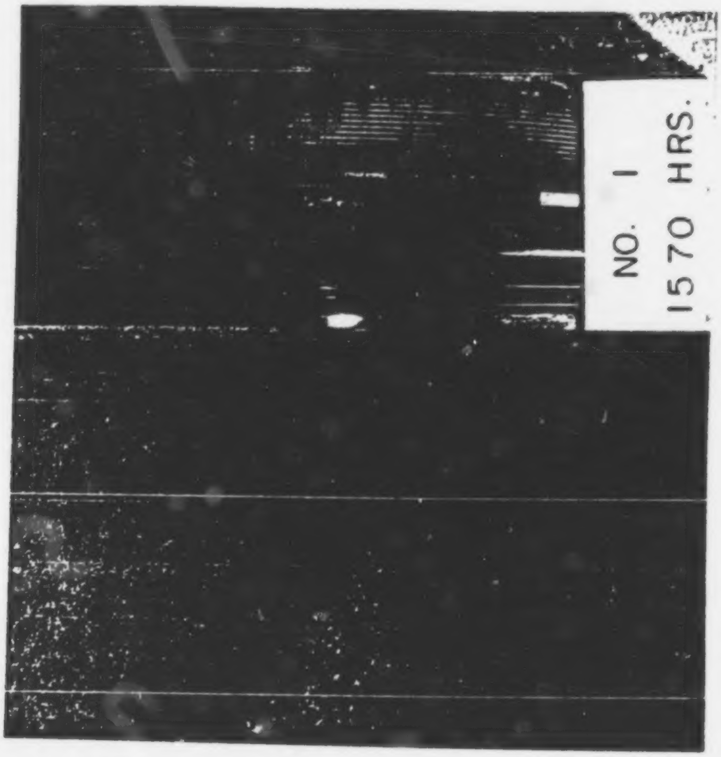


Figure 26. No. 1 piston after 1150 hours operation on fatty acids.

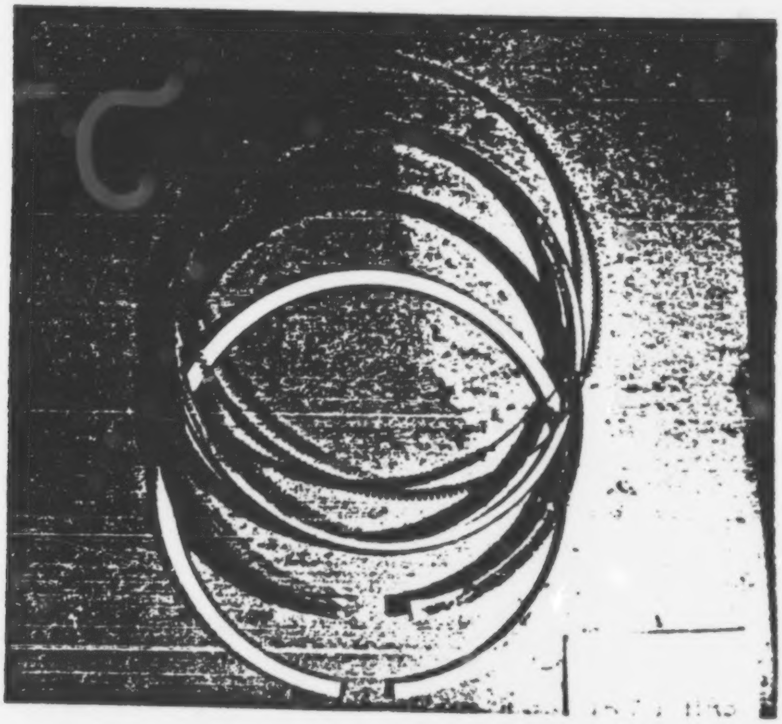


Figure 27. No. 1 piston rings after 1150 hours operation on fatty acids.

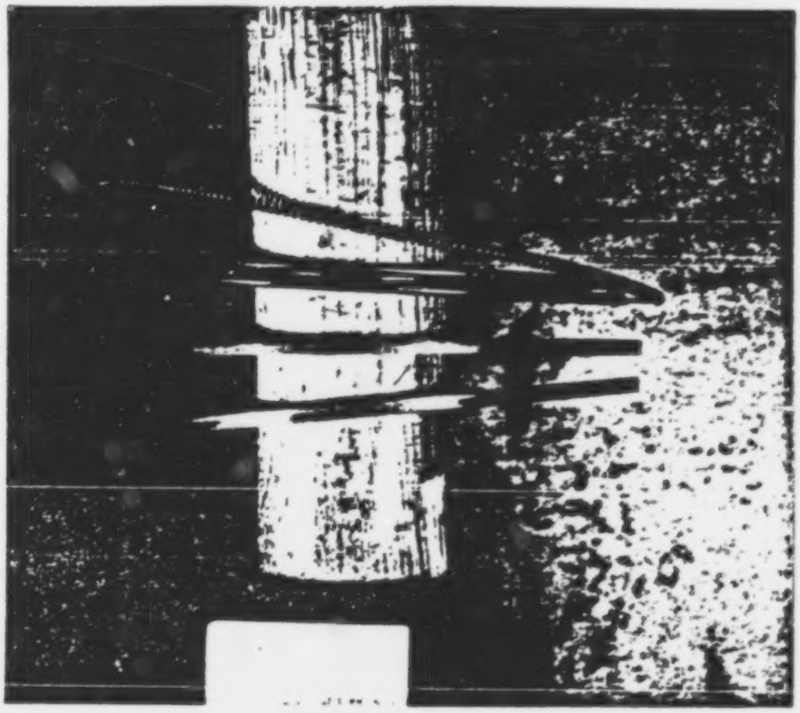


Figure 28. No. 1 piston rings after 1150 hours operation on fatty acids.

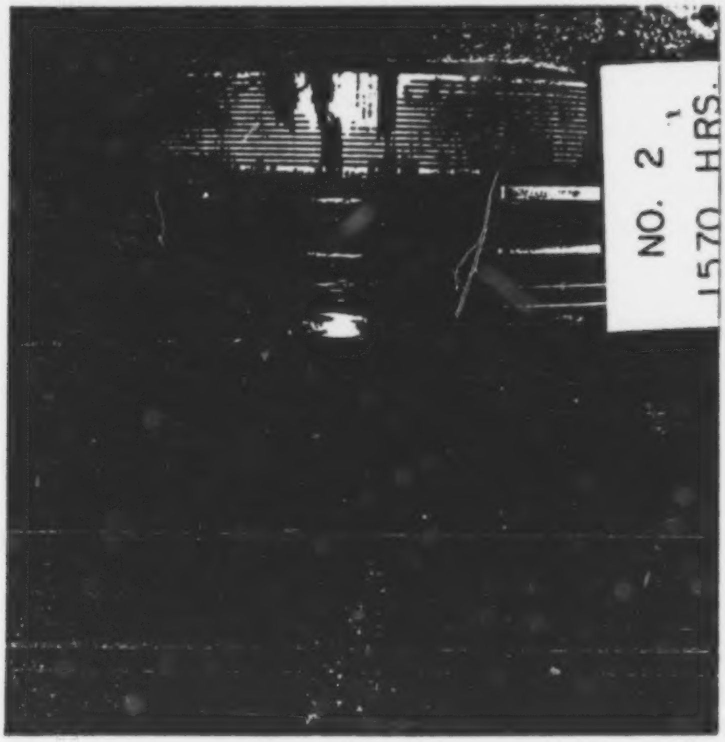


Figure 29. No. 2 piston after 1150 hours operation on fatty acids. Note scuffing.

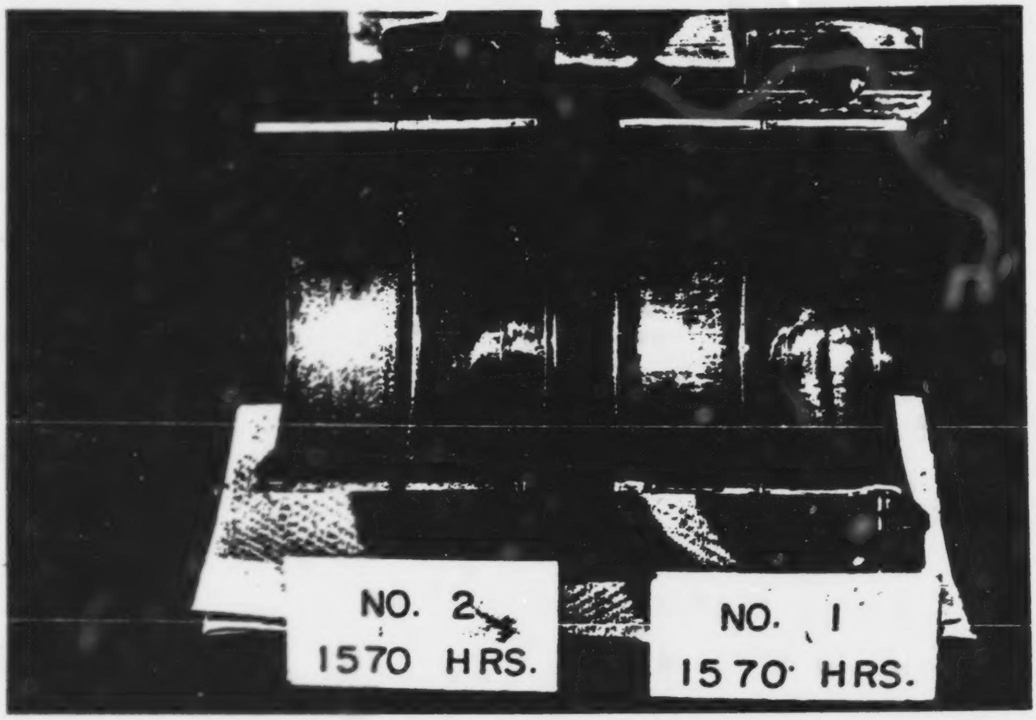

NO. 2
1570 HRS.
NO. 1
1570 HRS.

Figure 30. No. 1 and No. 2 Connecting rod bearings after 1570 hours operation on fatty acids.

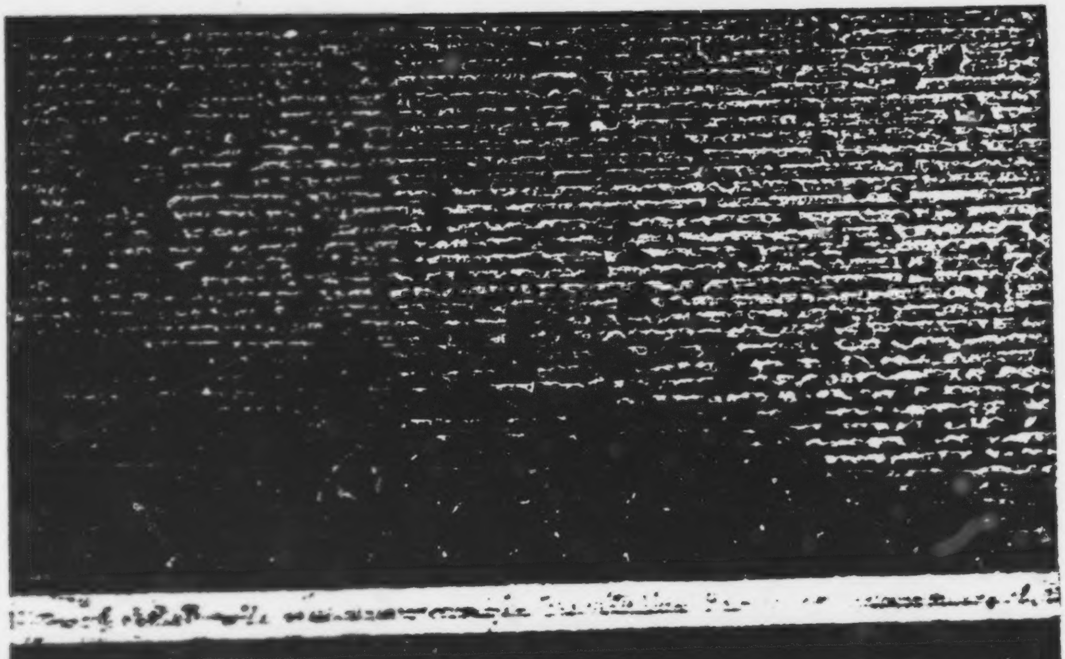


Figure 31. Enlarged view of No. 2 Connecting rod cap bearing after 1570 hours. Note corrosion pits (edge of bearing).

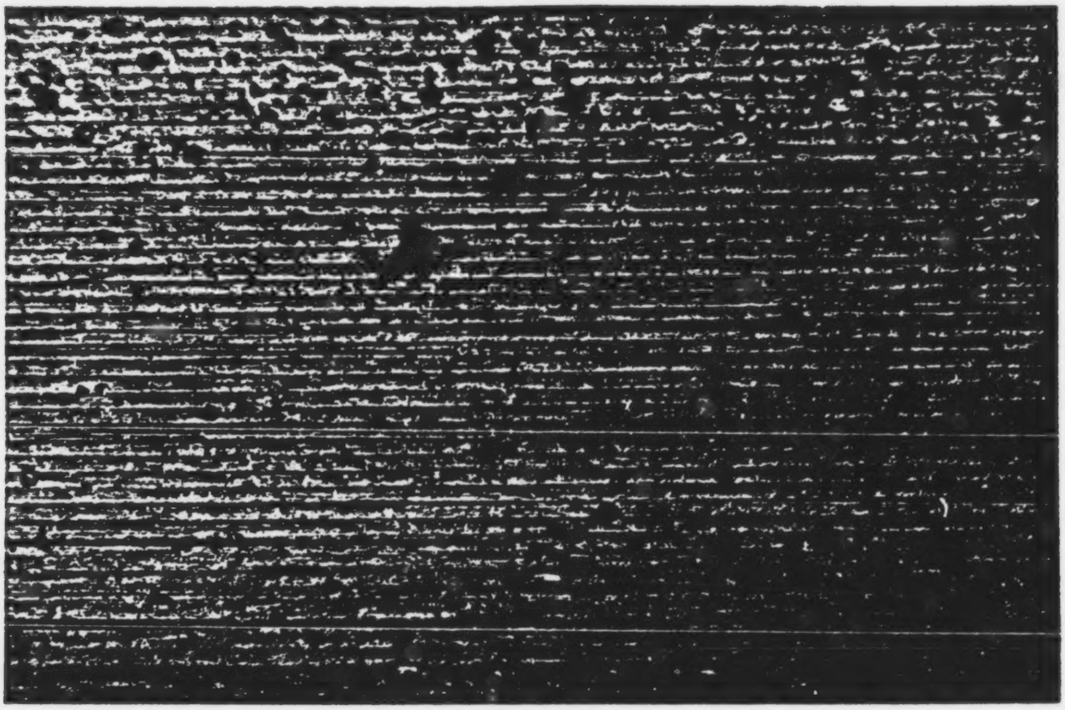


Figure 32. Enlarged view of No. 2 Connecting rod cap bearing after 1570 hours.

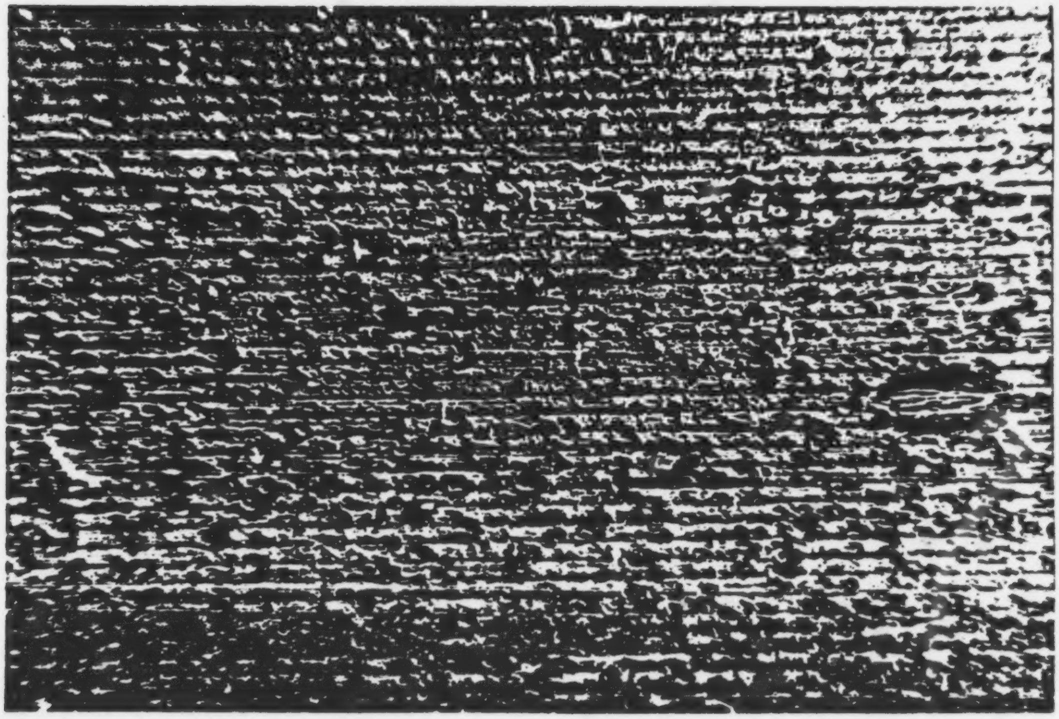


Figure 33. Englarged view of No. 2 Connecting rod cap bearing after 1570 hours.

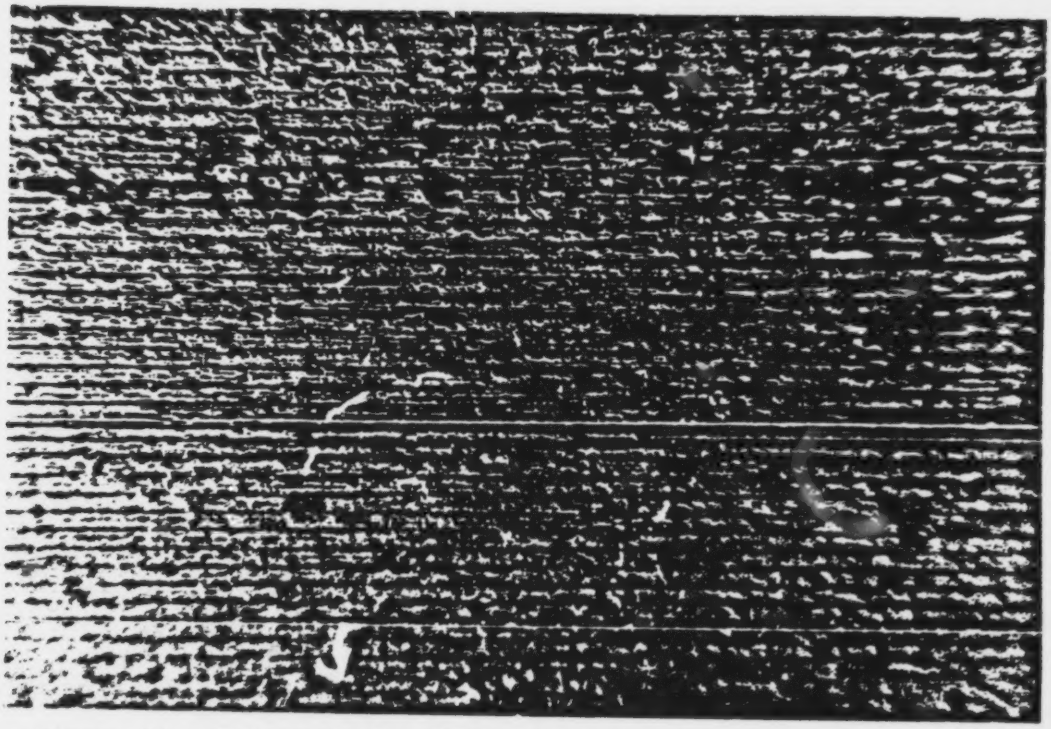


Figure 34. Enlarged view of No. 2 Connecting rod cap bearing after 1570 hours.

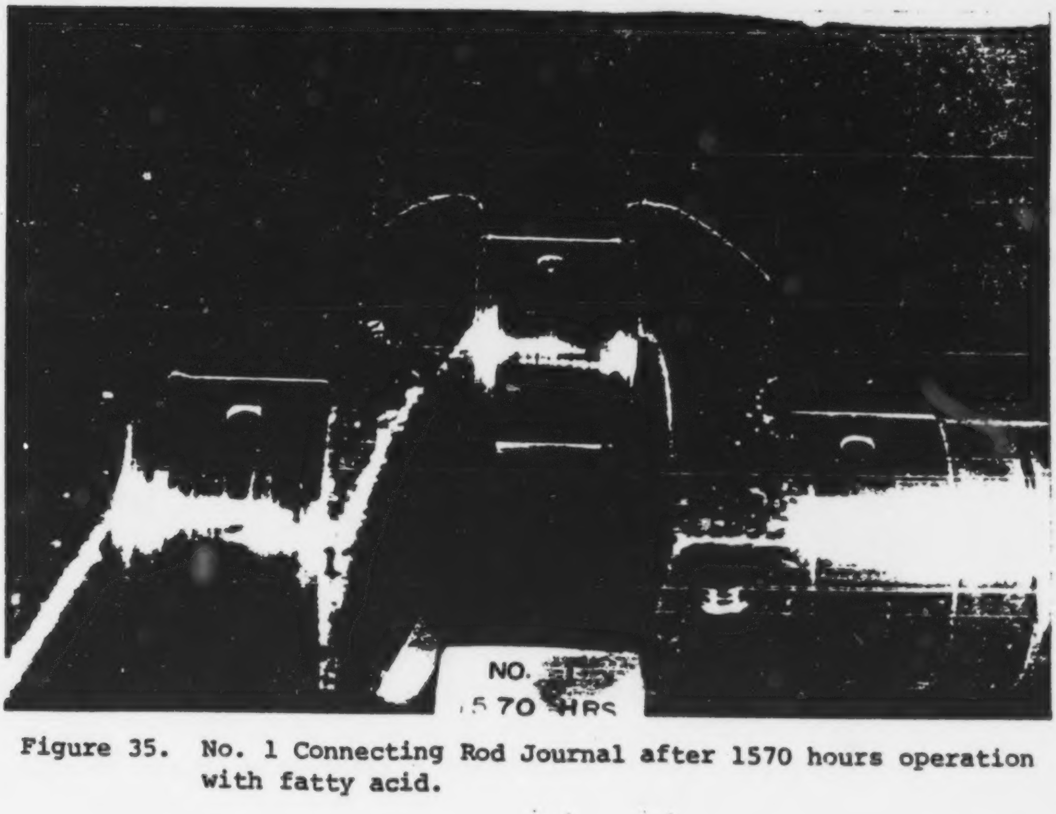


Figure 35. No. 1 Connecting Rod Journal after 1570 hours operation with fatty acid.

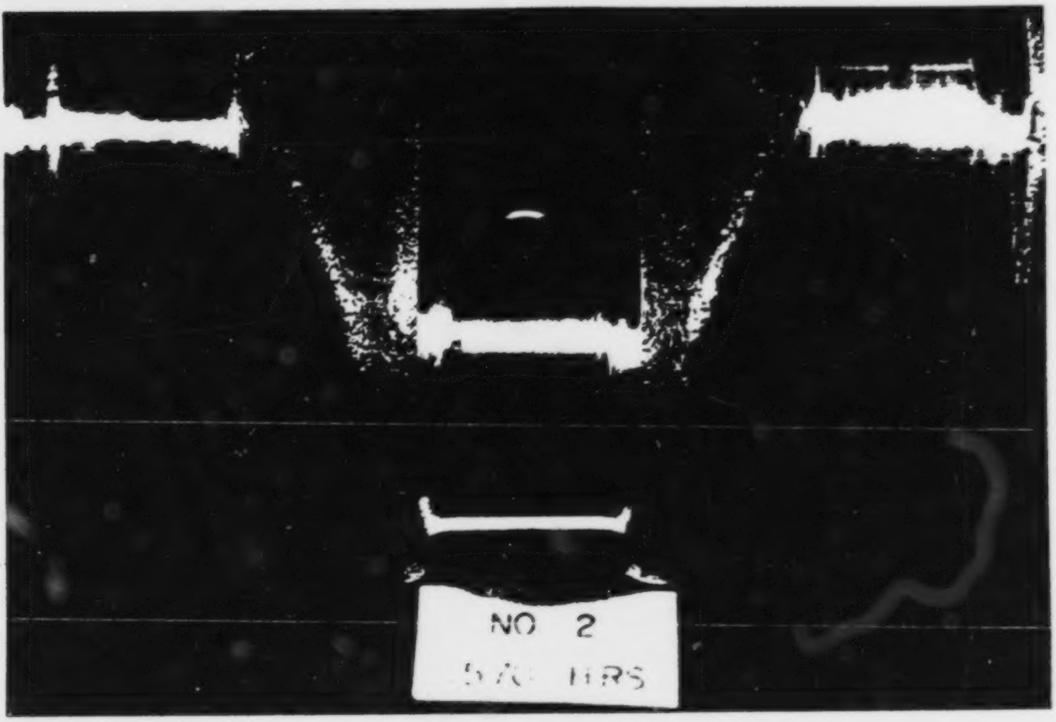


Figure 36. No. 2 Connecting Rod Journal after 1570 hours operation with fatty acid.

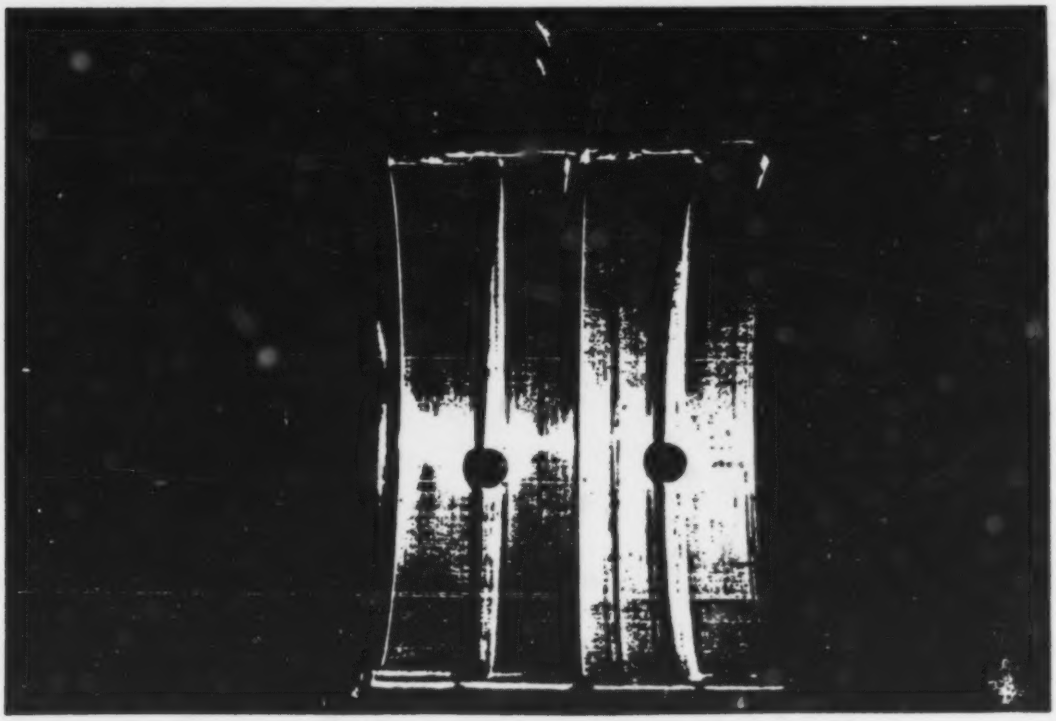


Figure 37. Centre main bearing after 1570 hours operation with fatty acid.

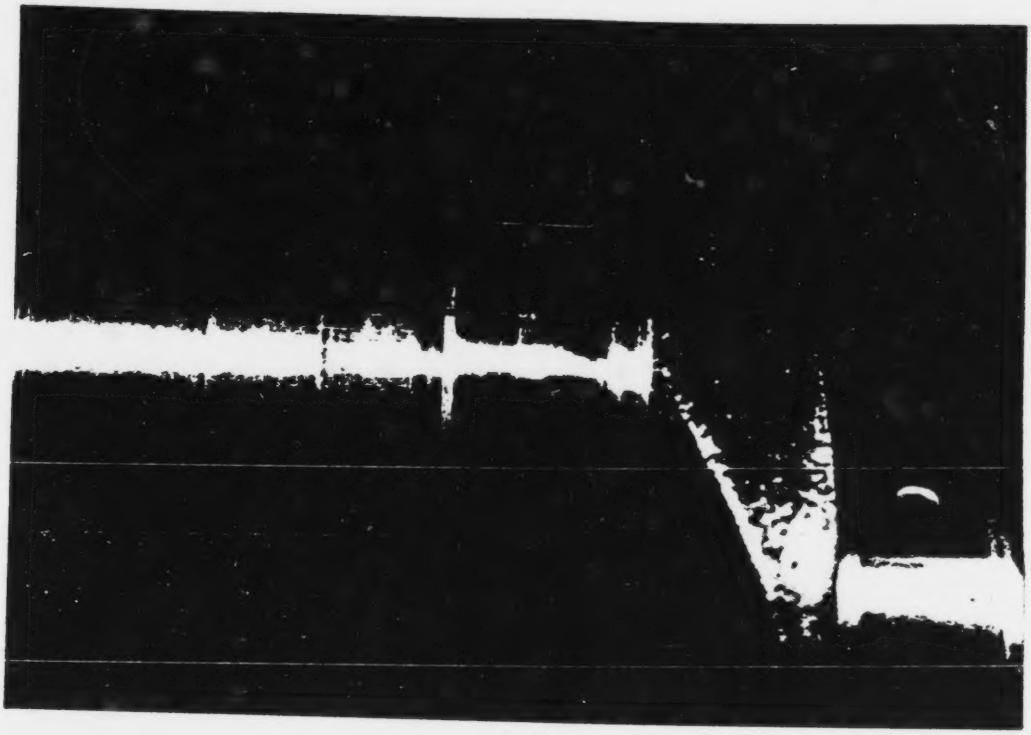


Figure 38. Front crankshaft journal after 1570 hours operation with fatty acid.

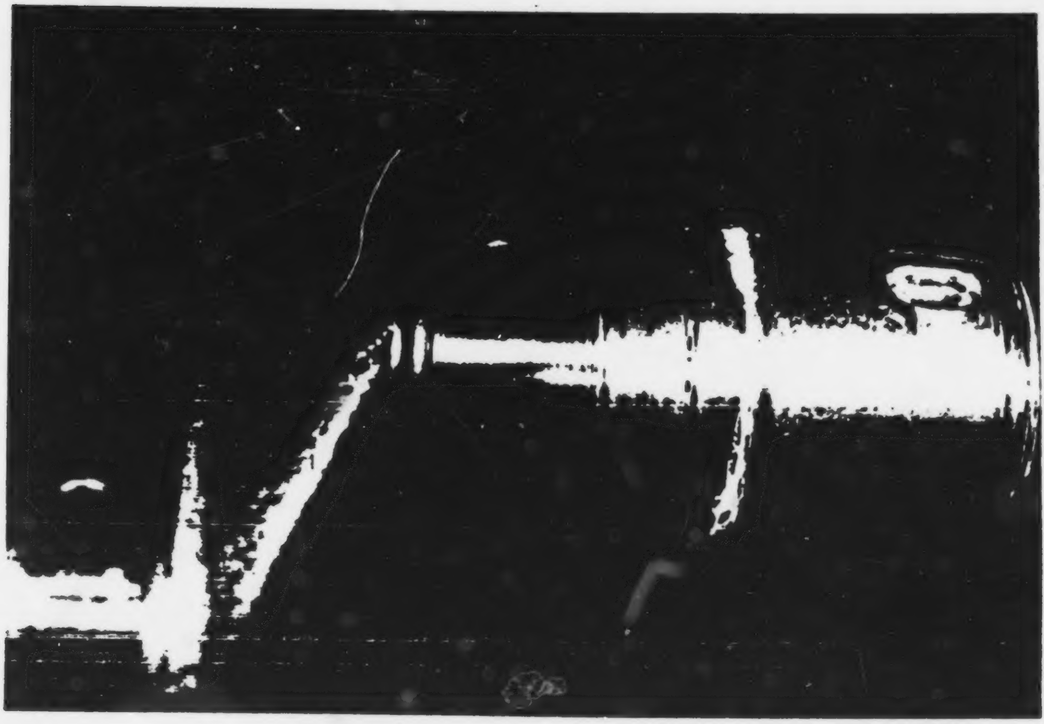


Figure 39. Rear crankshaft journal after 1570 hours operation with fatty acid.

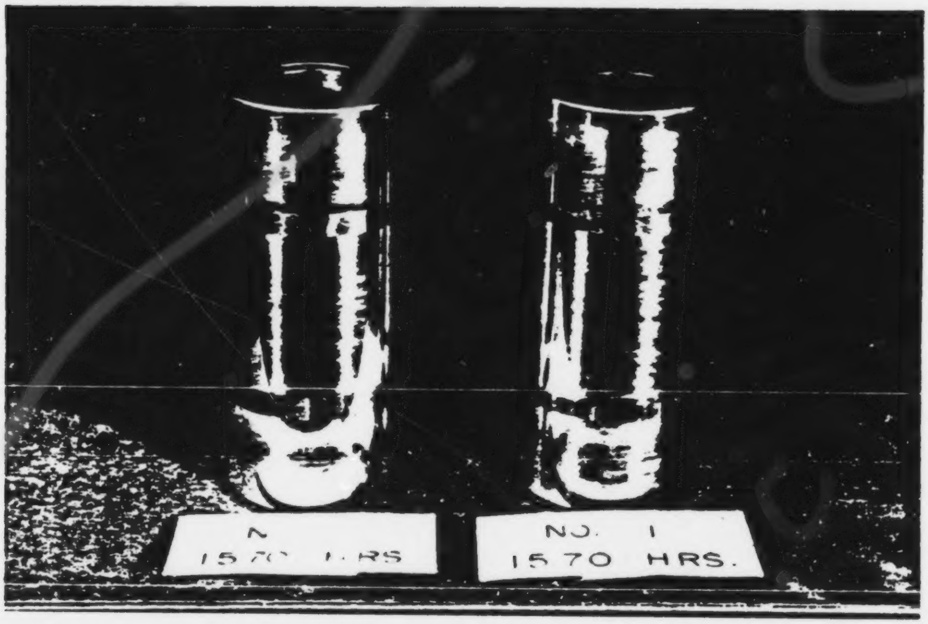

NO. 1
1570 HRS.

Figure 40. No. 1 and No. 2 Piston rod pins after 1150 hours operation with fatty acid.

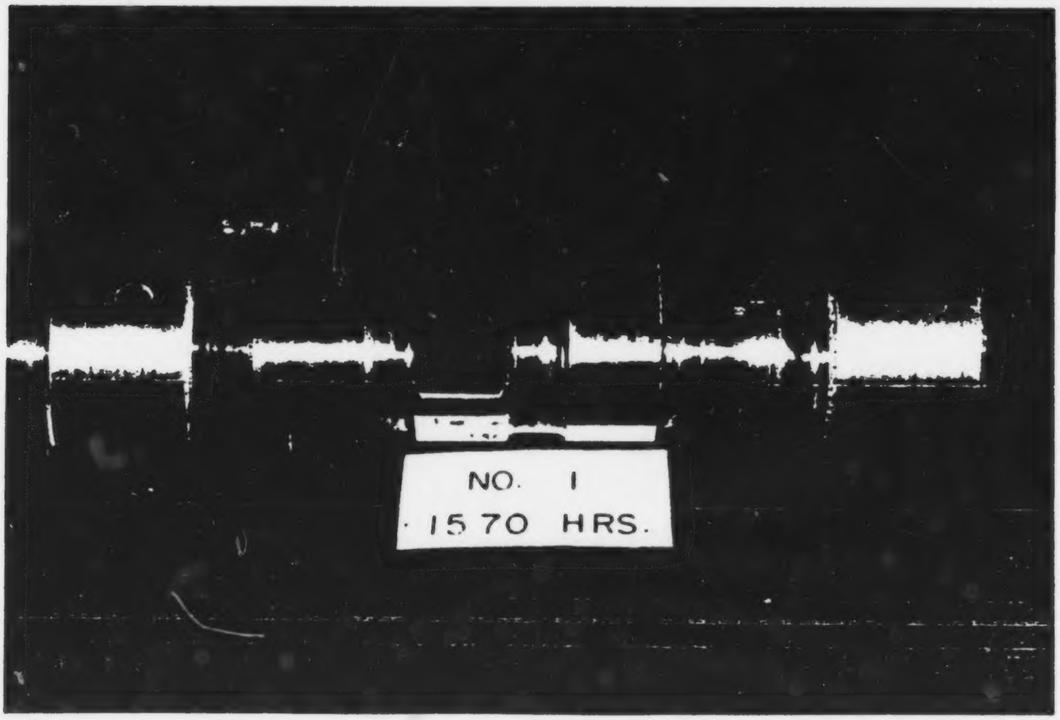

NO. 1
1570 HRS.

Figure 41. Camshaft lobes for No. 1 cylinder after 1570 hours operation with fatty acid.

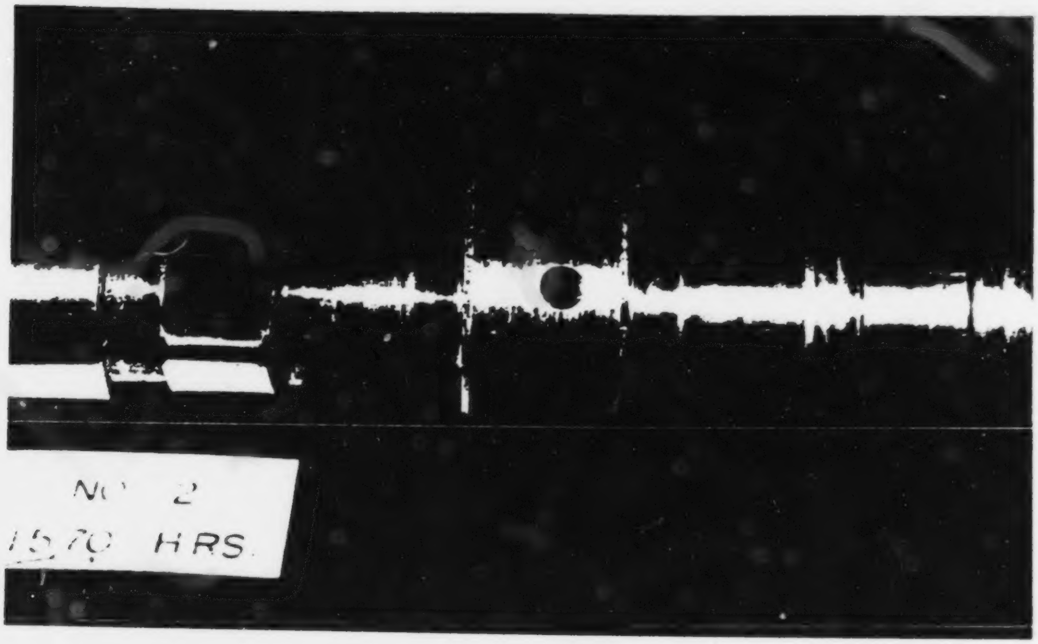

NO. 2
1570 HRS.

Figure 42. Camshaft centre journal after 1570 hours operation with fatty acid.

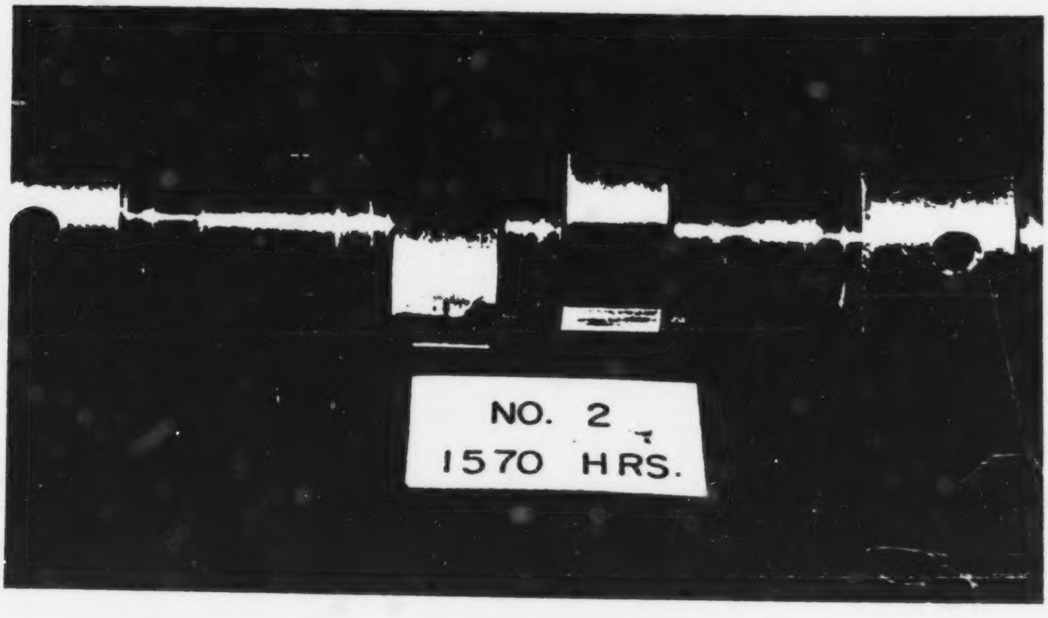

NO. 2
1570 HRS.

Figure 43. Camshaft lobes for No. 2 cylinder after 1570 hours operation with fatty acid.

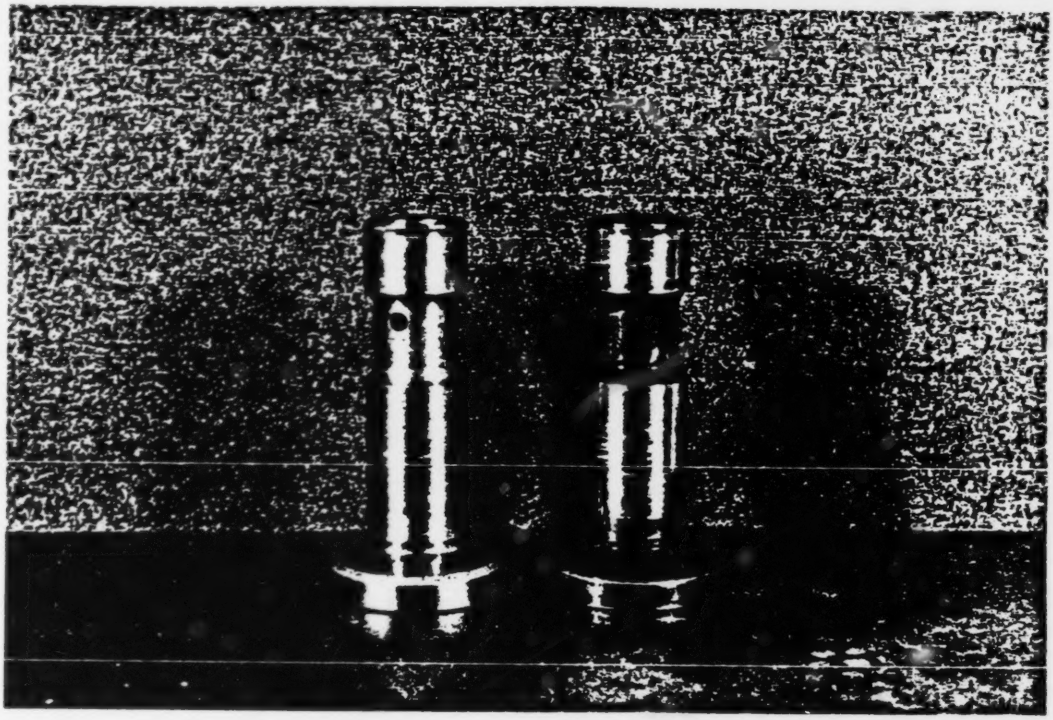


Figure 44. Cam followers after 1570 hours operation with fatty acid. Note deposit on follower on the right side; left follower was cleaned.

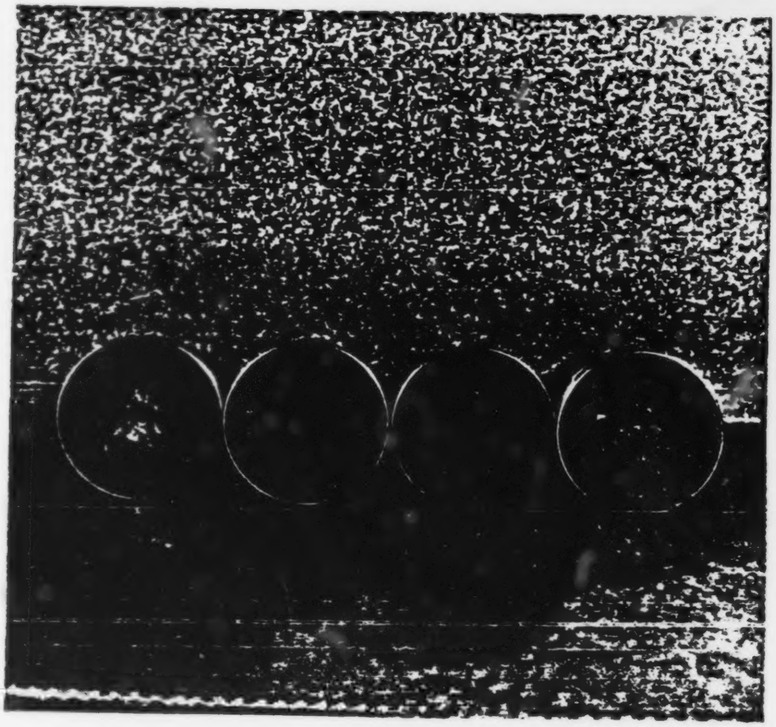


Figure 45. Cam followers after 1570 hours, note pitting on surfaces in contact with the cam lobes.

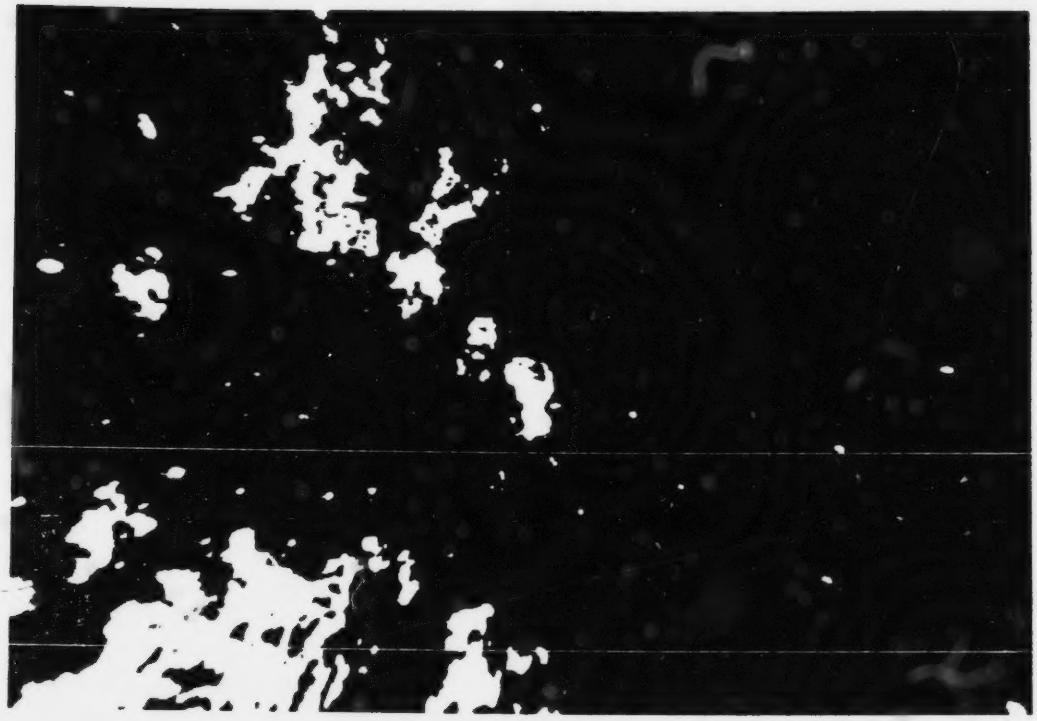


Figure 46. Enlarged view of pitting on cam follower shown in Figure 45.

Figure 47. Close-up view of fuel injector nozzle tips after 205 hours. Note coke build-up on tip. Injector tips on right side shows corrosion pits around fuel port holes after 562 hours.

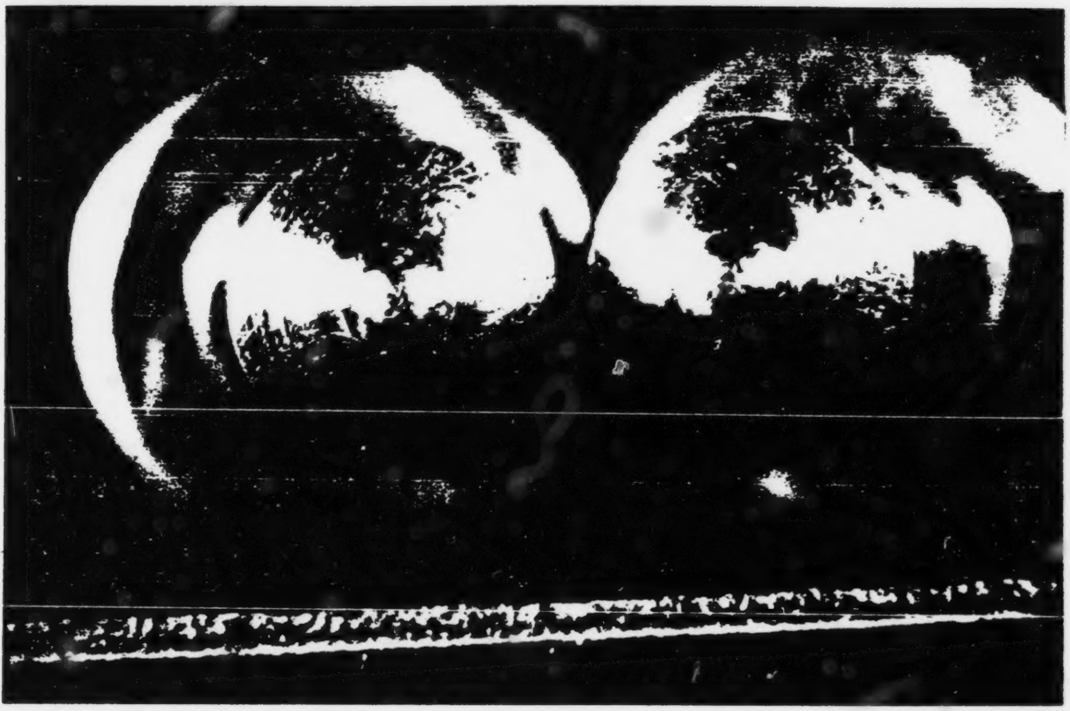


Figure 48. Close-up view of fuel injector nozzle tips after cleaning 562 hours of operation. Note corrosion.

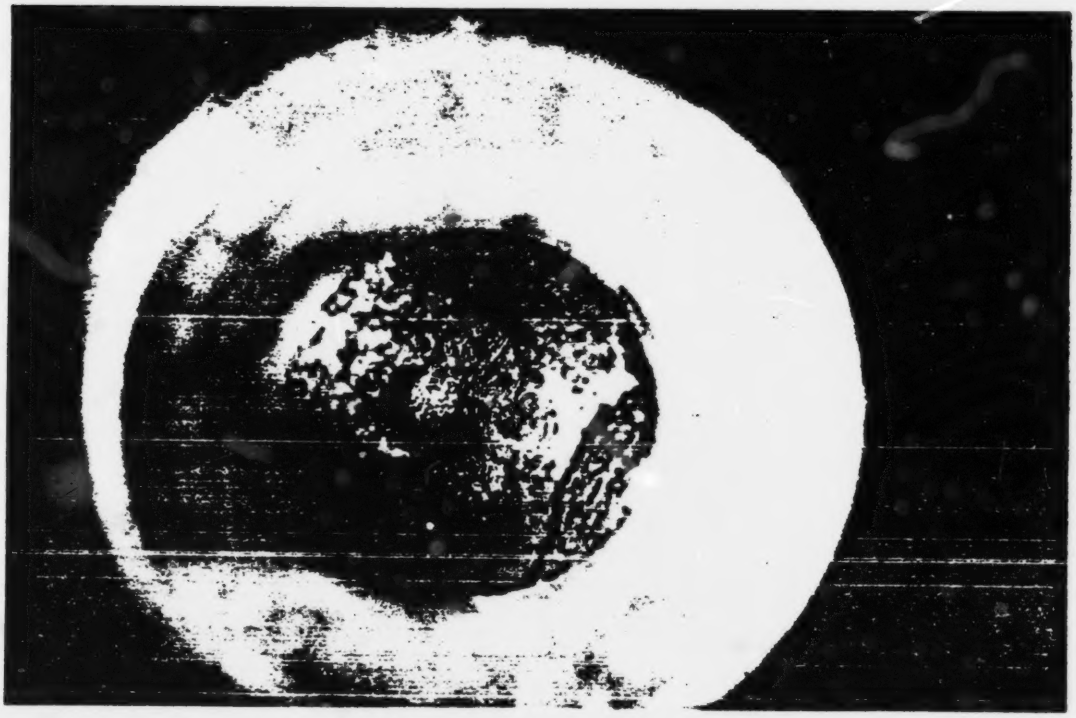


Figure 49. Close-up view of coke accumulation on fuel injector nozzle tip after 205 hours.

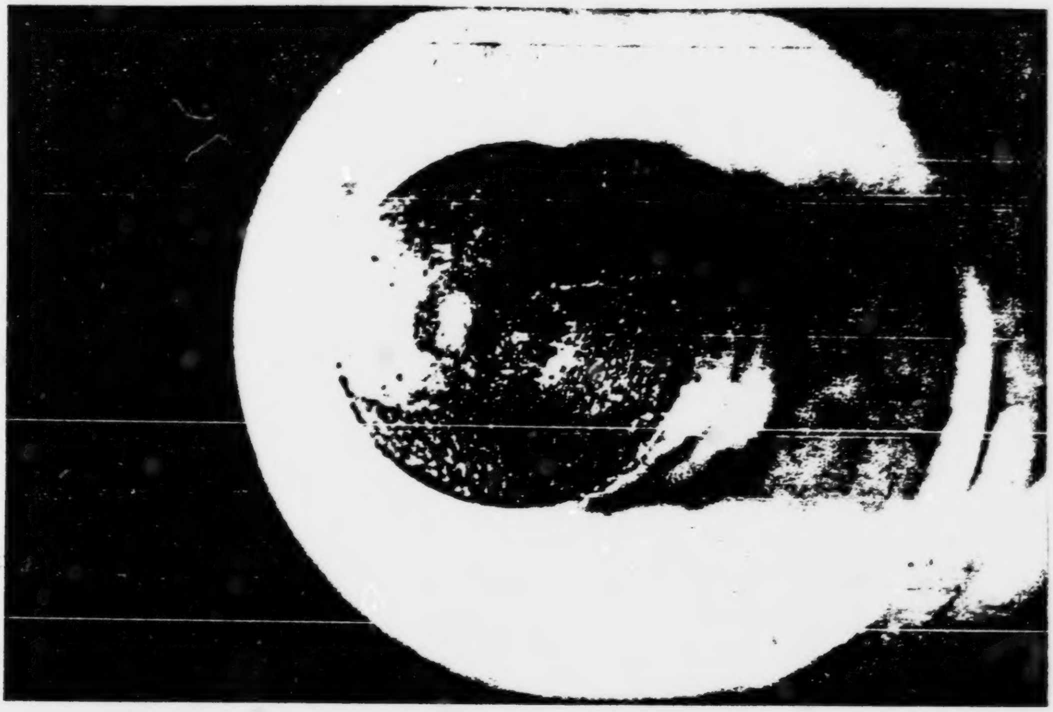


Figure 50. Close-up view of coke accumulation on fuel injector nozzle tip after 205 hours.

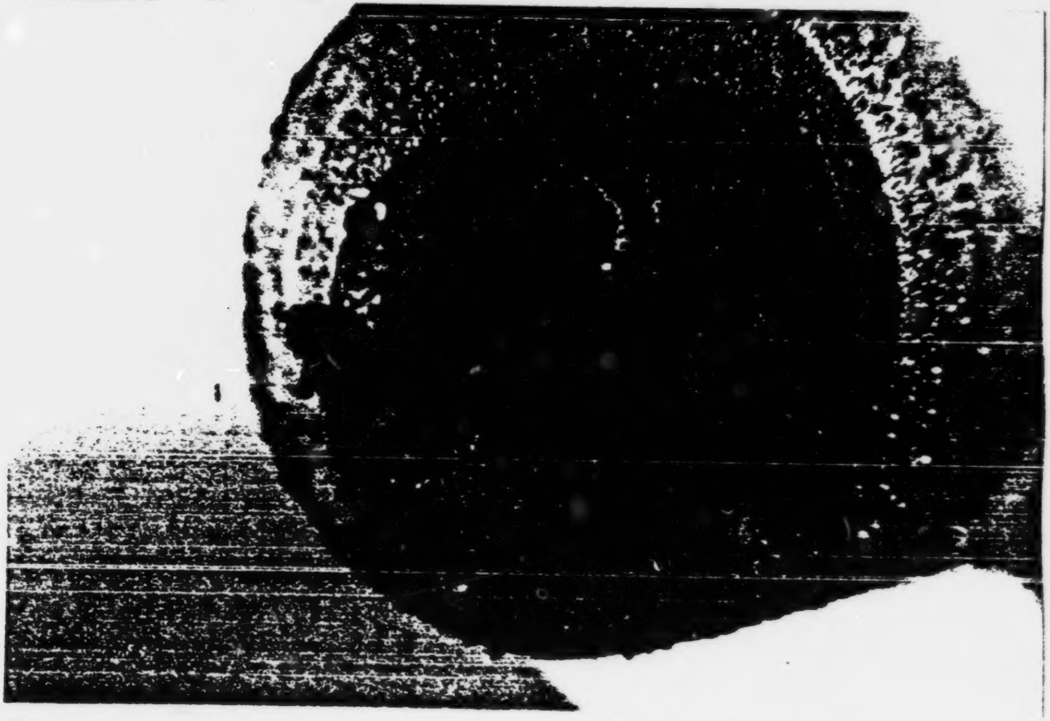


Figure 51. Close-up view of coke accumulation on fuel injector nozzle tip after 205 hours. Note volcano-like shape deposits around fuel port holes.

APPENDIX A

GRAPHICAL RESULTS
OF
SPECIFIC FUEL CONSUMPTION VERSUS ENGINE POWER
WITH
ENGINE SPEED @ 2000 RPM

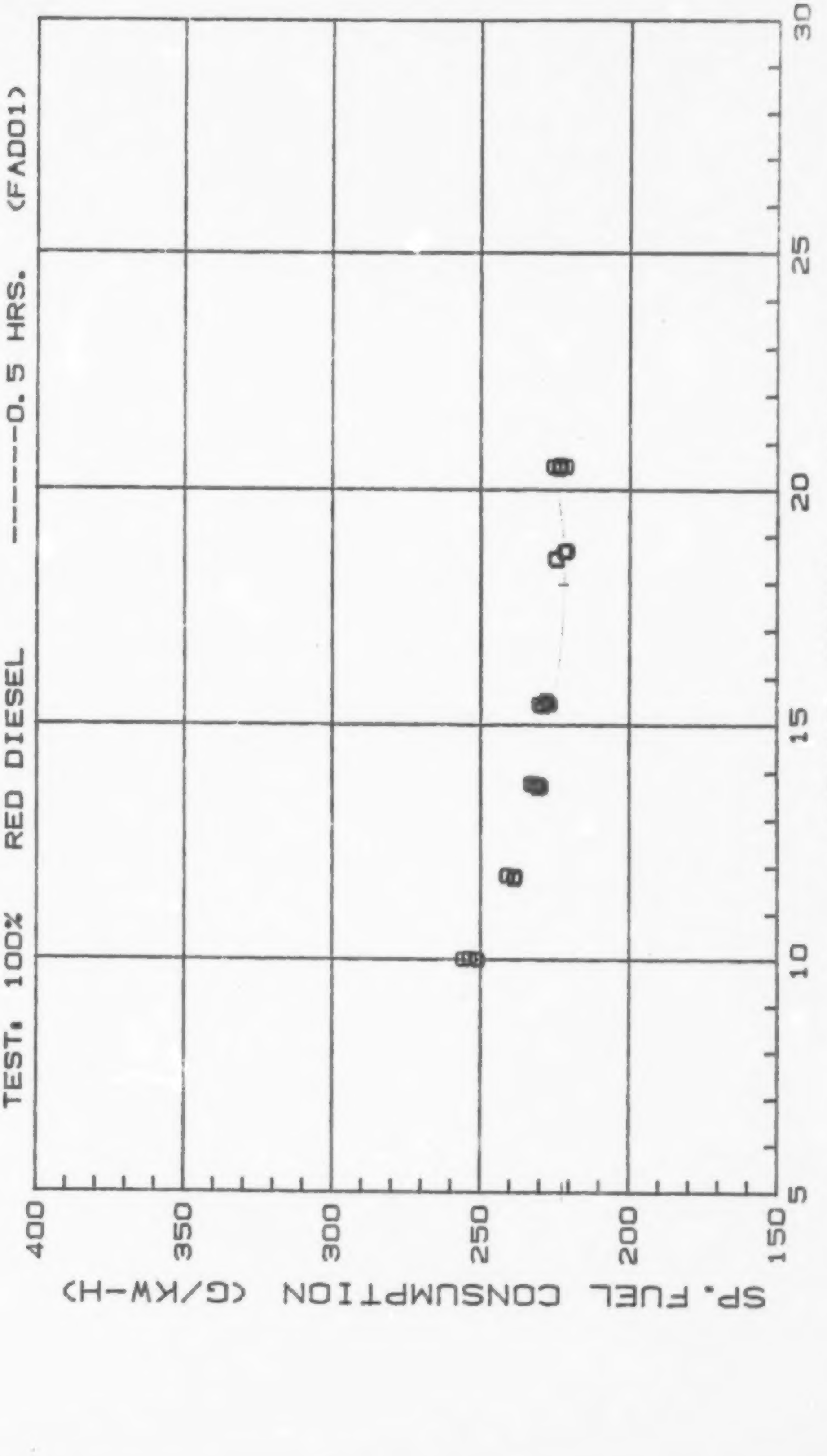
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. MAY 28.1985 -ENGINE. DEUTZ F2L912 2 CYL.

TEST. 100% RED DIESEL ------0.5 HRS. (FAD01)



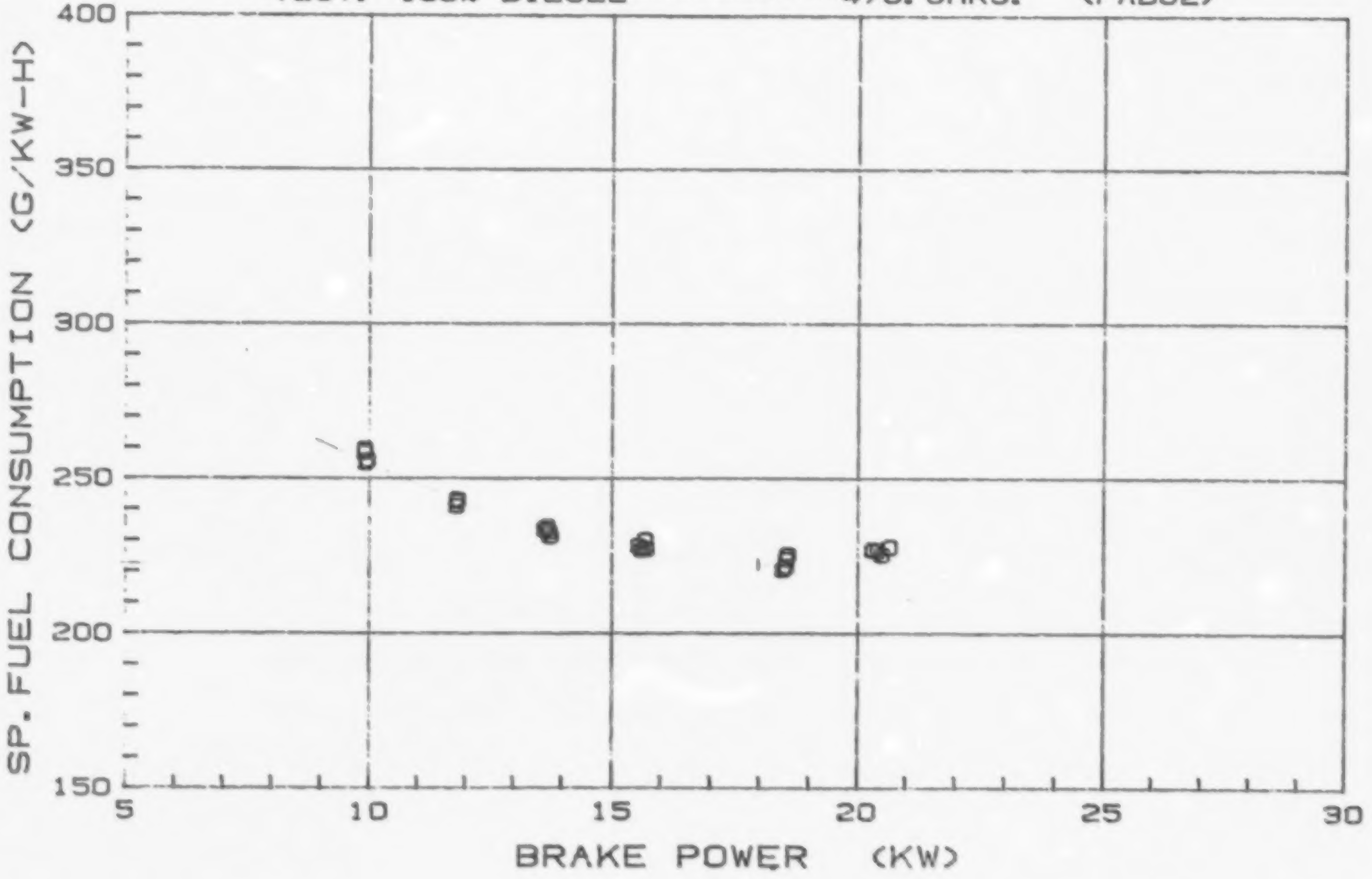
UNIVERSITY OF SASKATCHEWAN–FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: AUG. 1,1985 –ENGINE: DEUTZ·F2L912 2 CYL.

TEST: 100% DIESEL----------478.9HRS. (FAD02)



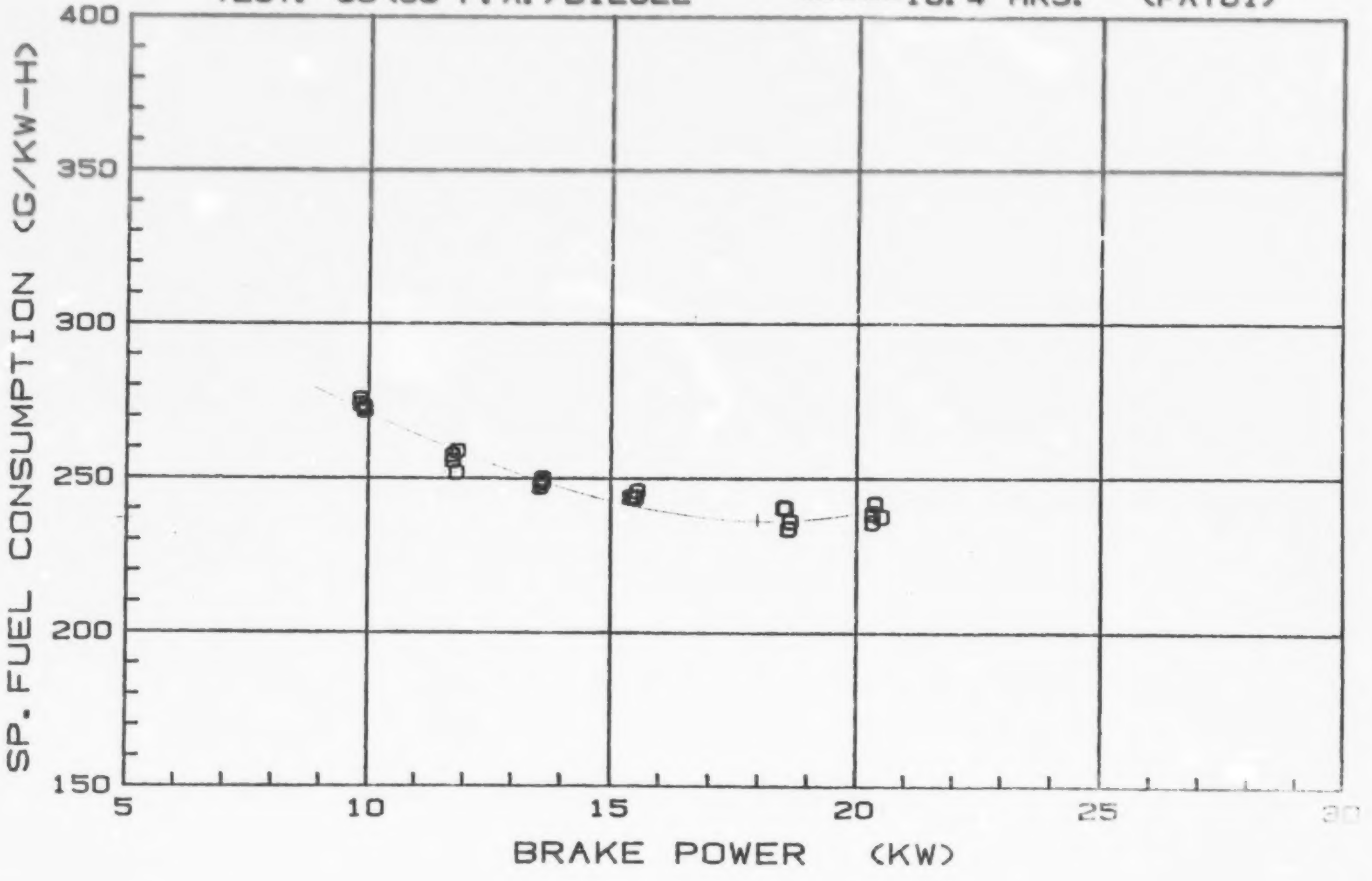
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAY 29, 1985 -ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50\50 F. A. /DIESEL -----18. 4 HRS. (FAT01)



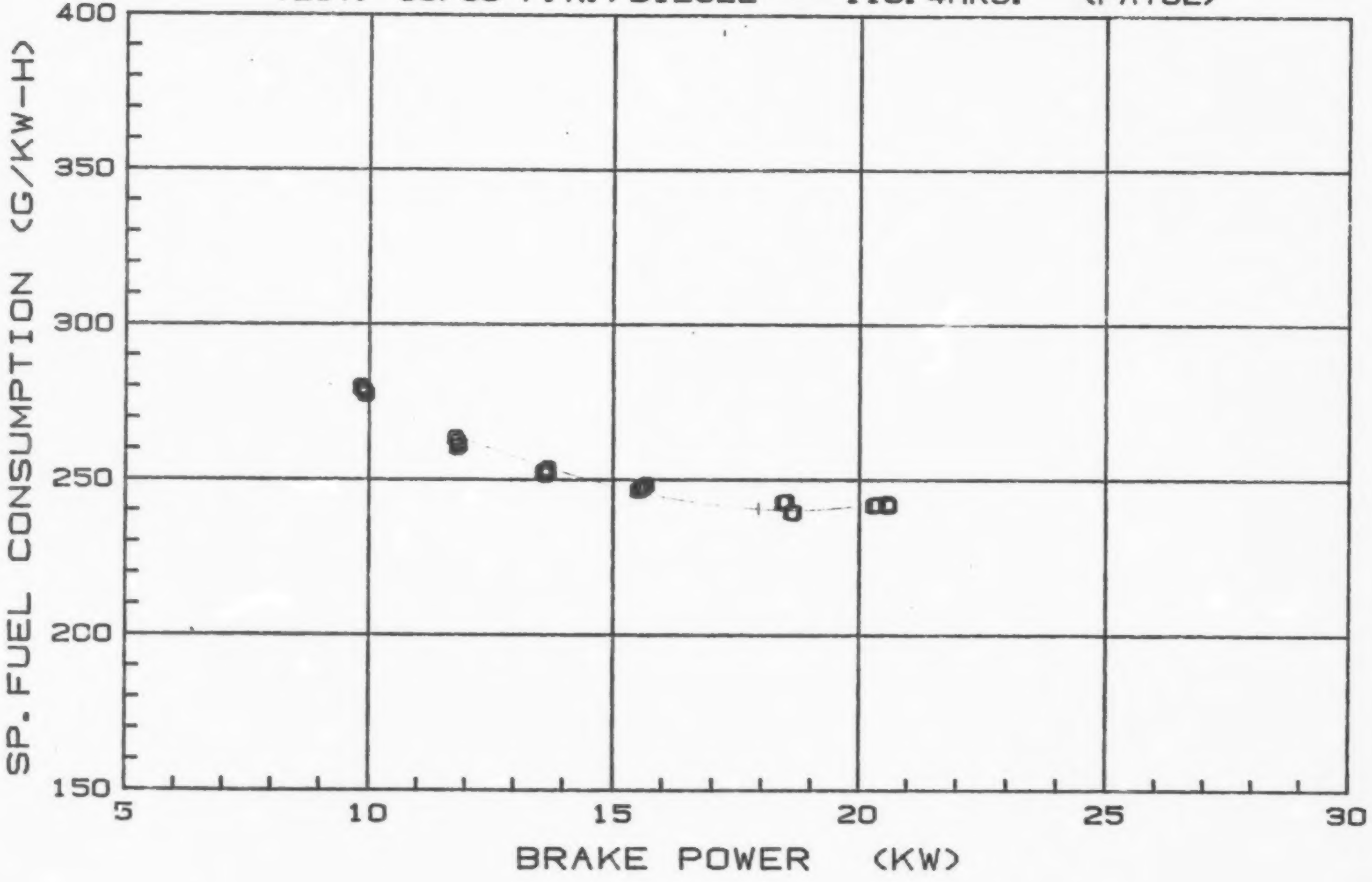
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTJRAL ENGINEERING *AERD*

DATE: JUNE 4, 1985 -ENGINE: DEUTZ.F2L912 2 CYL.

TEST: 50/50 F.A./DIESEL----110.4HRS. (FAT02)



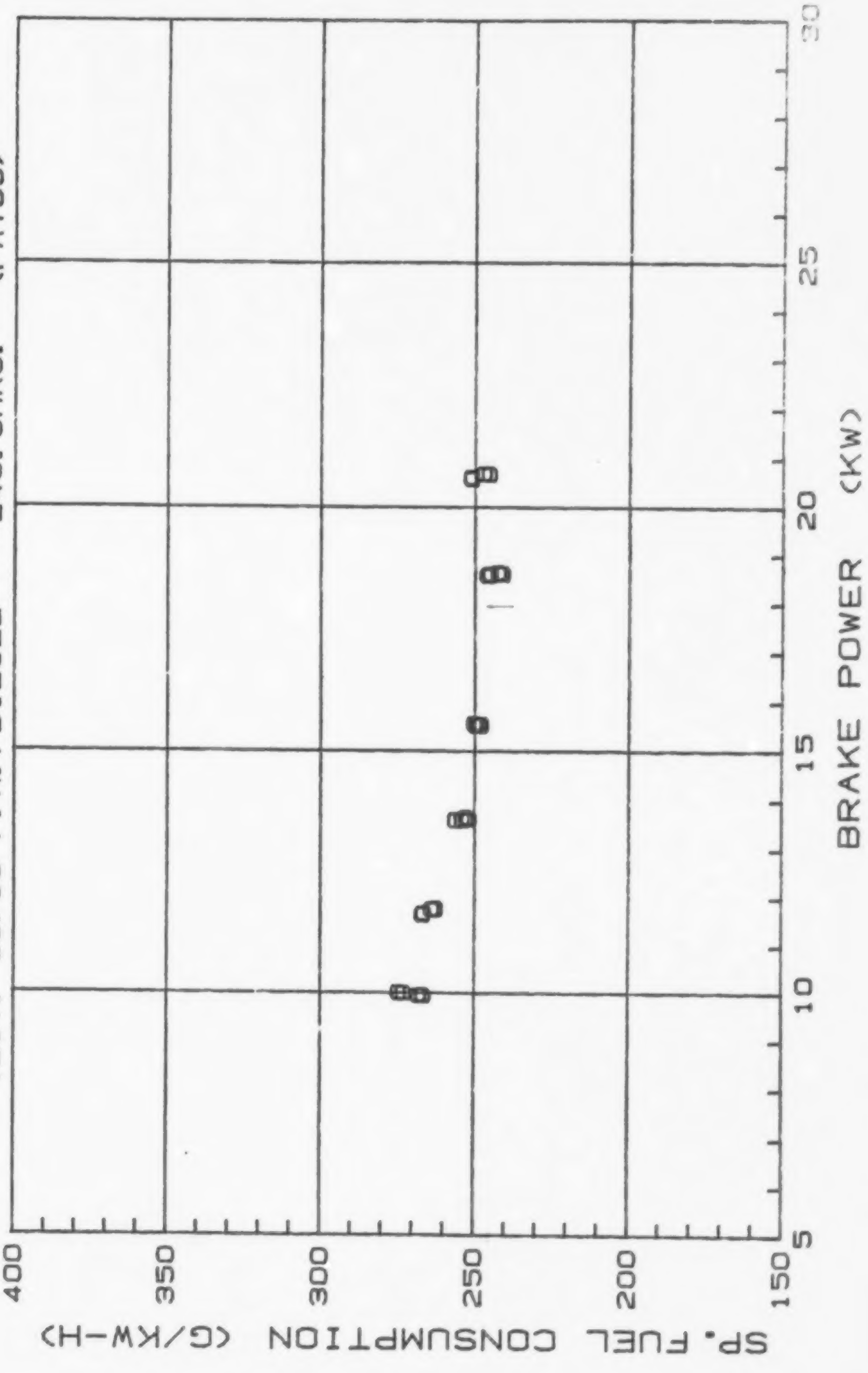
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. JUNE 14.1985 -ENGINE. DEUTZ F2L912 2 CYL.

TEST. 50/50 F.A./DIESEL----245.9HRS. (FAT03)



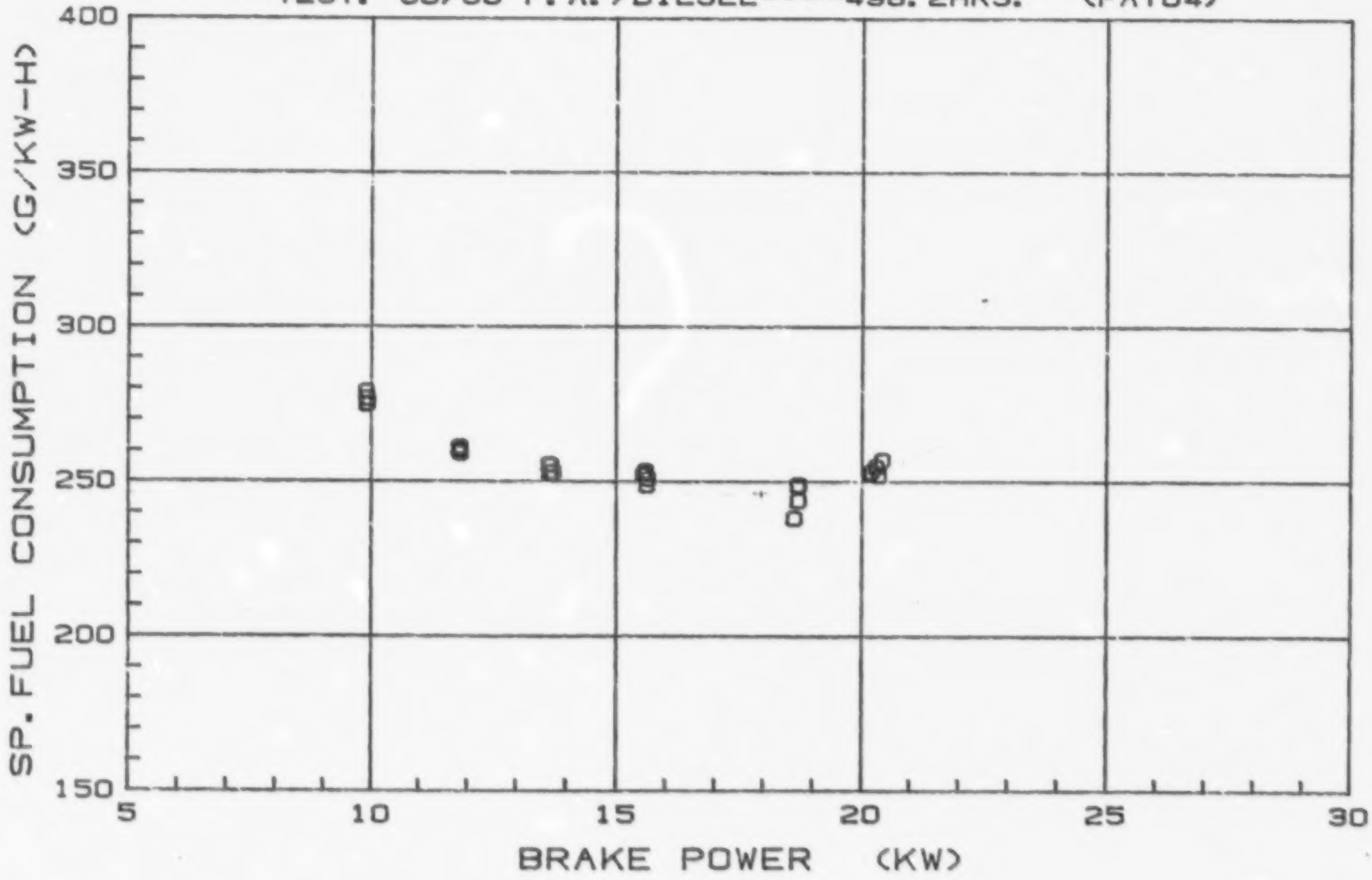
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

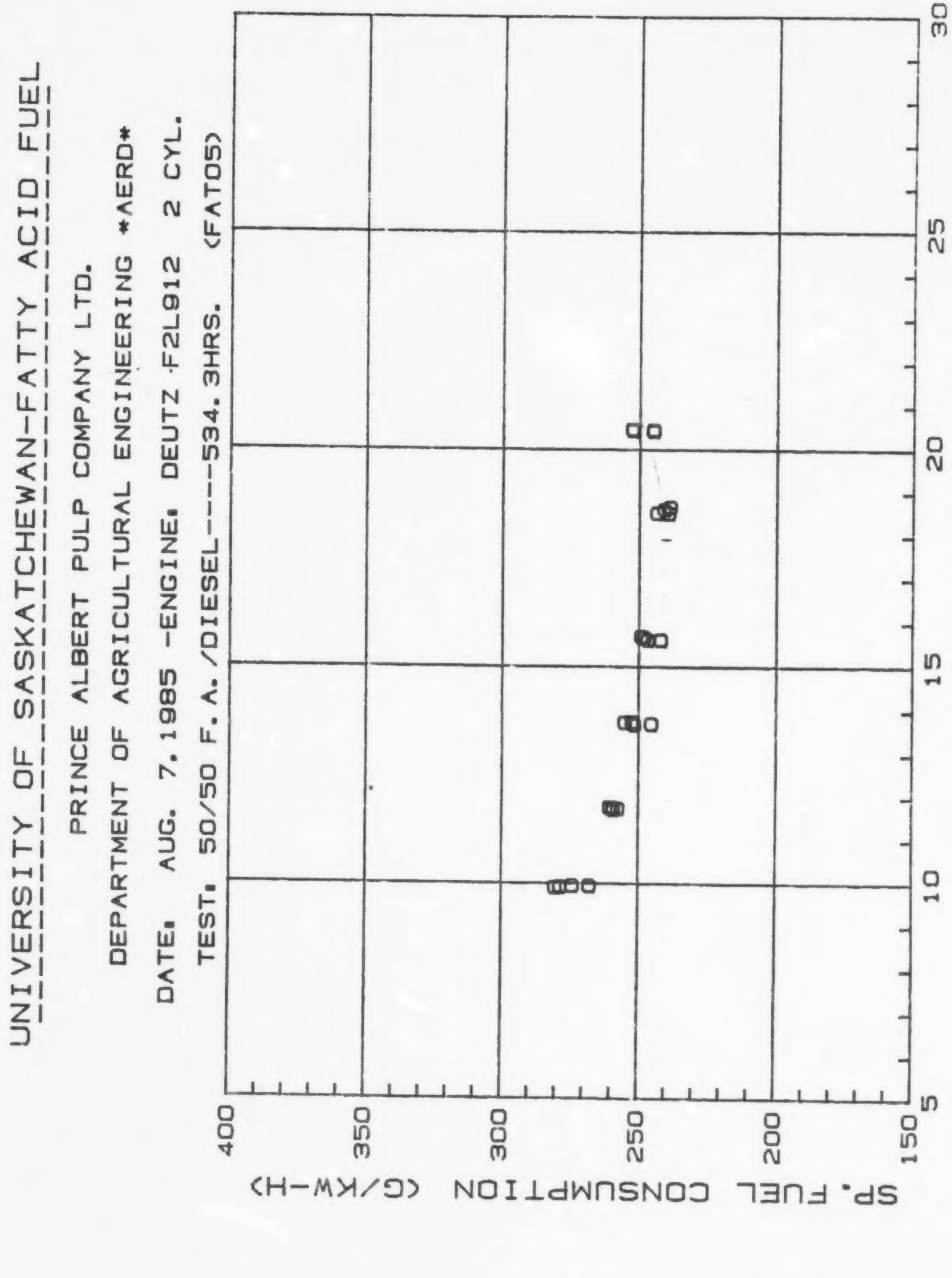
PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: AUG. 2. 1985 -ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50/50 F. A. /DIESEL----498. 2HRS. (FAT04)




UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL
PRINCE ALBERT PULP COMPANY LTD.
DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*
DATE. AUG. 7.1985 -ENGINE. DEUTZ F2L912 2 CYL.
TEST. 50/50 F.A./DIESEL----534.3HRS. (FAT05)
400
350
300
250
200
150
SP. FUEL CONSUMPTION (G/KW-H)
5
10
15
20
25
30
BRAKE POWER (KW)

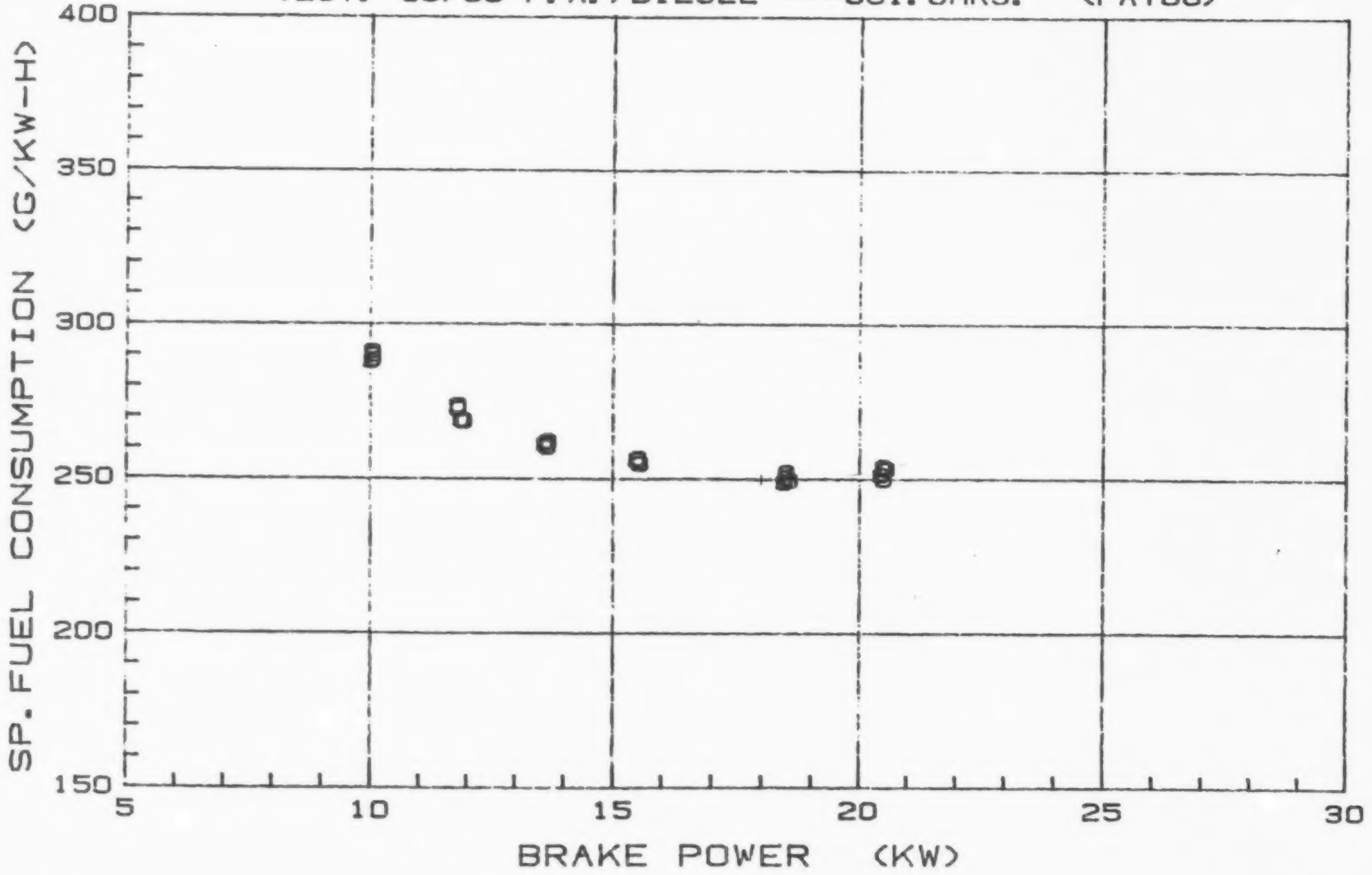
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. AUG. 26, 1985 -ENGINE. DEUTZ F2L912 2 CYL.

TEST. 50/50 F. A. /DIESEL----861.8HRS. (FAT06)



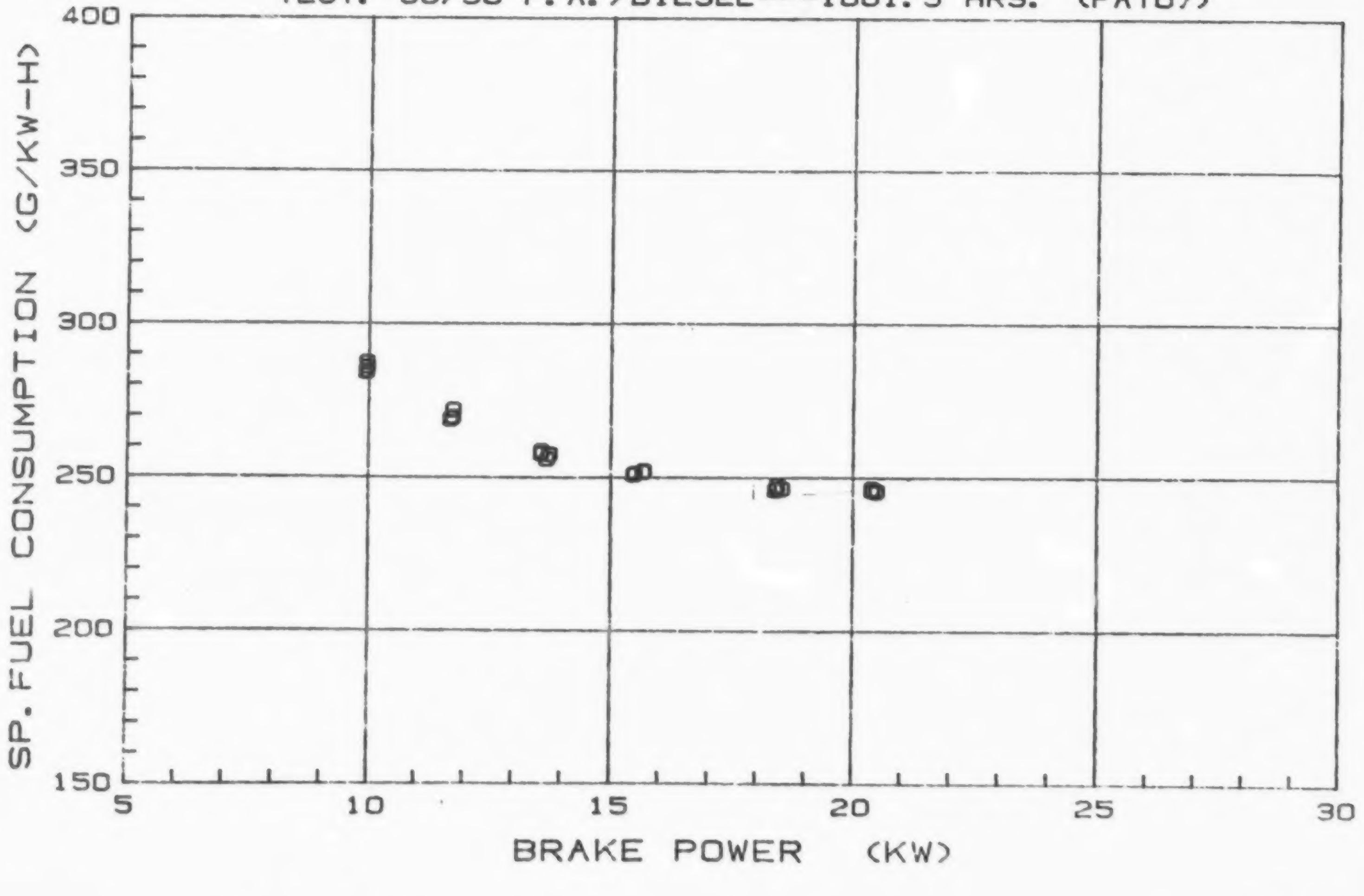
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

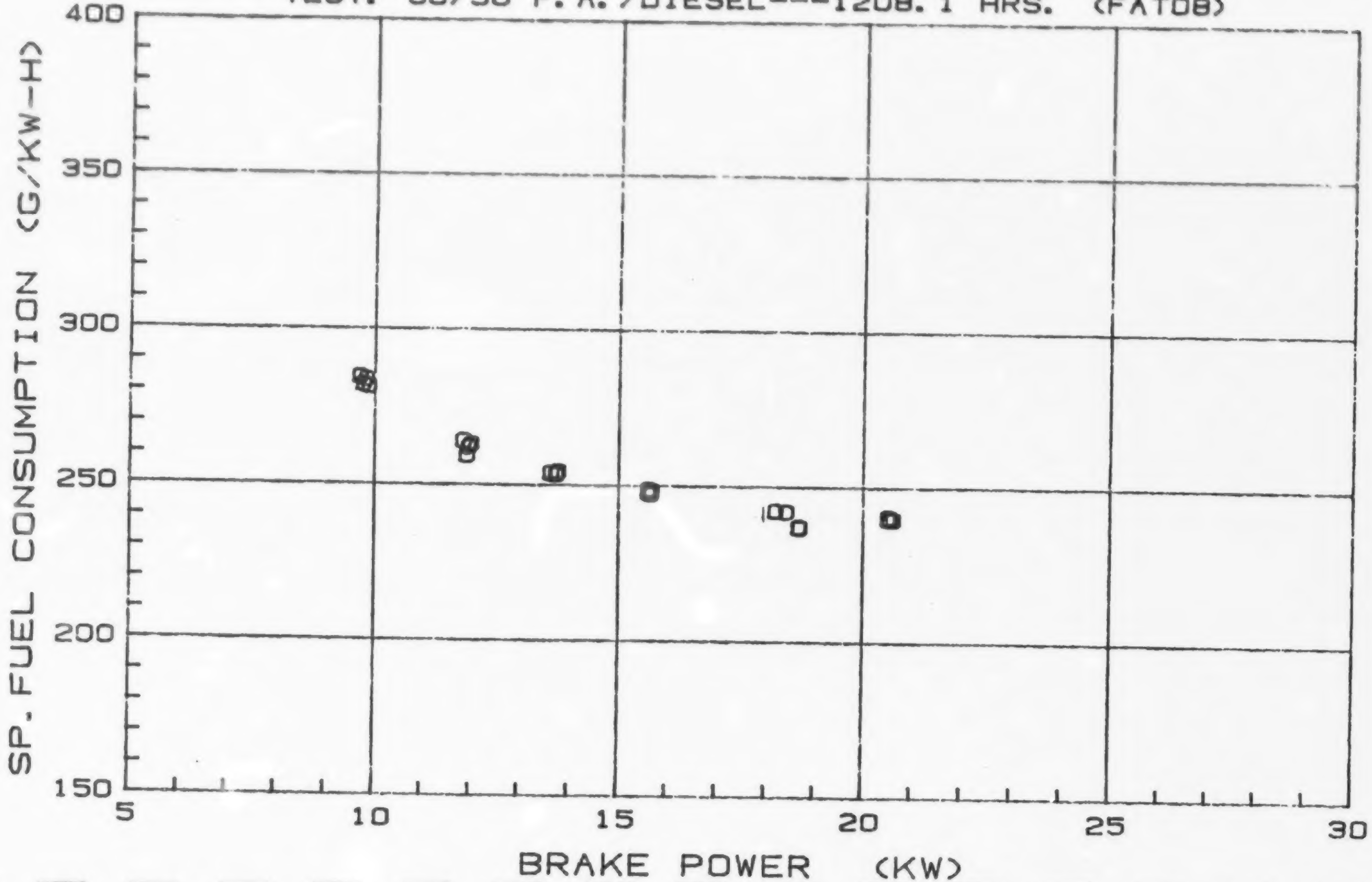
PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. SEPT. 9, 1985 -ENGINE. DEUTZ F2L912 2 CYL.

TEST. 50/50 F.A./DIESEL---1001.5 HRS. (FAT07)





UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: SEPT. 20. 1985 -ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50/50 F.A./DIESEL---1208.1 HRS. (FAT08)

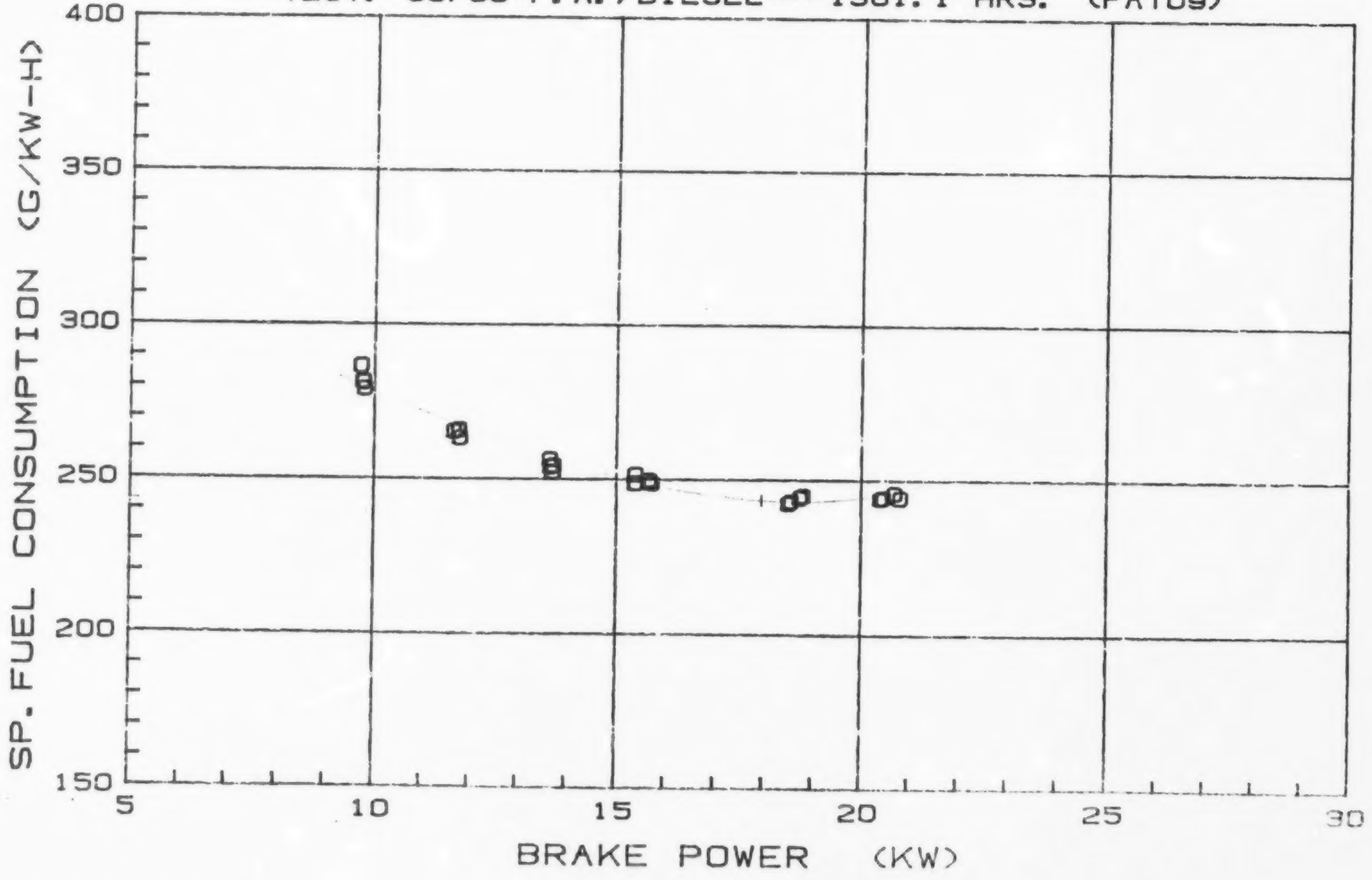
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: OCT. 02. 1985 -ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50/50 F. A. /DIESEL---1361. 1 HRS. (FAT09)



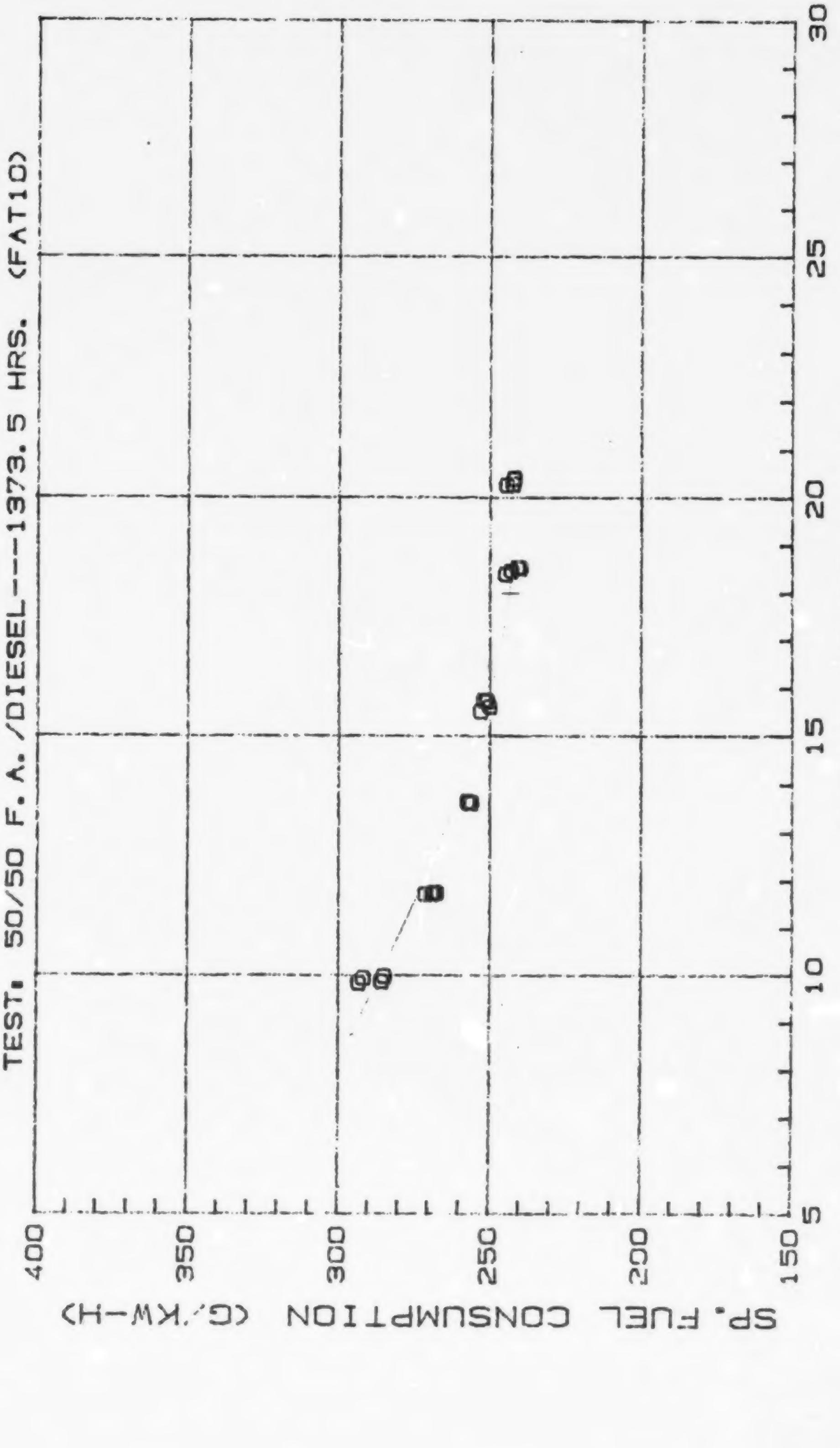
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. OCT.07,1985 -ENGINE. DEUTZ F2L912 2 CYL.

TEST. 50/50 F.A./DIESEL---1373.5 HRS. (FAT10)



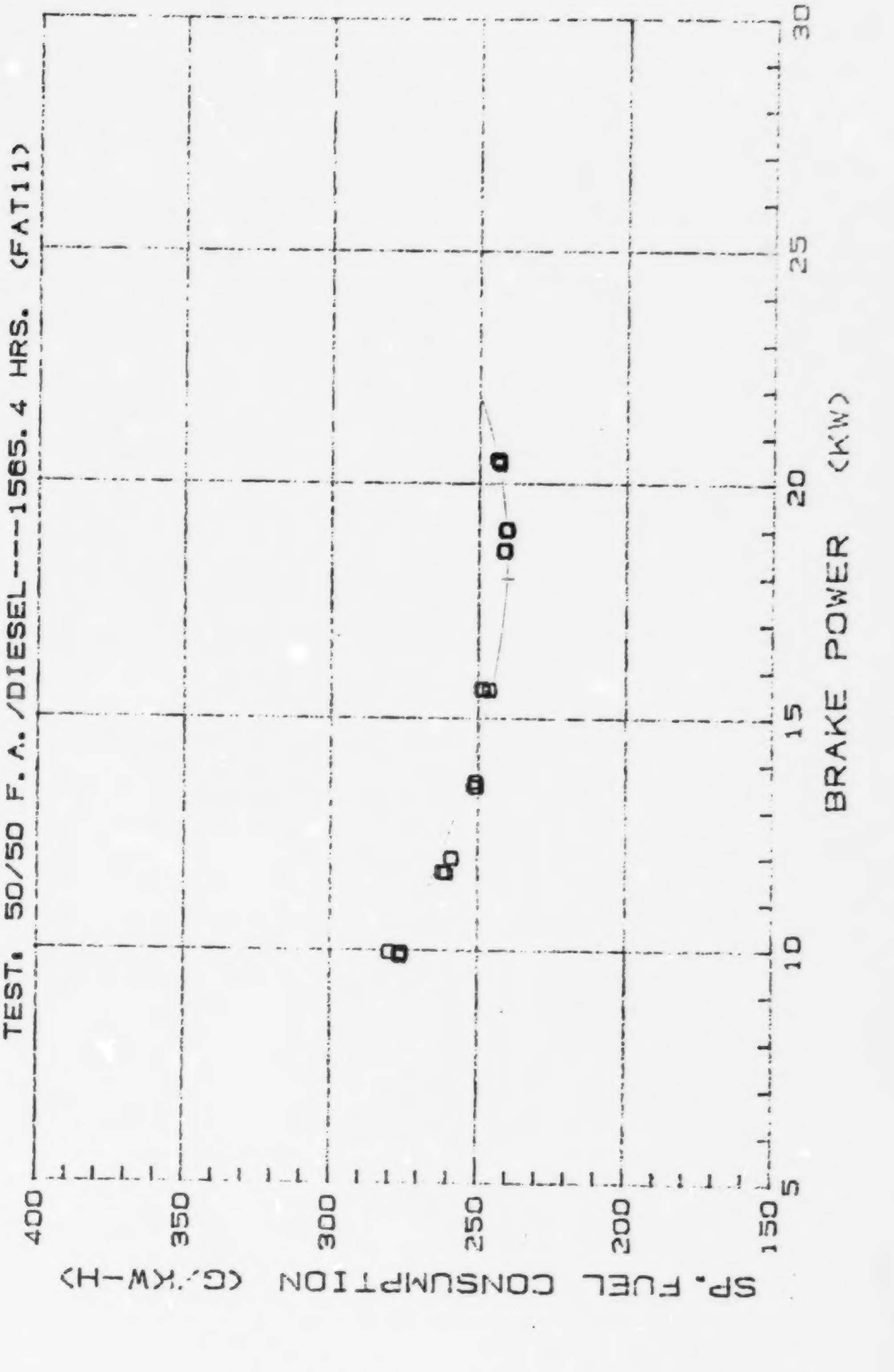
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE, OCT.28,1985 -ENGINE, DEUTZ F2L912 2 CYL.

TEST, 50/50 F.A./DIESEL---1565.4 HRS. (FAT11)



APPENDIX B

GRAPHICAL RESULTS
OF
MAXIMUM ENGINE POWER DETERMINATIONS
POWER VERSUS ENGINE SPEED

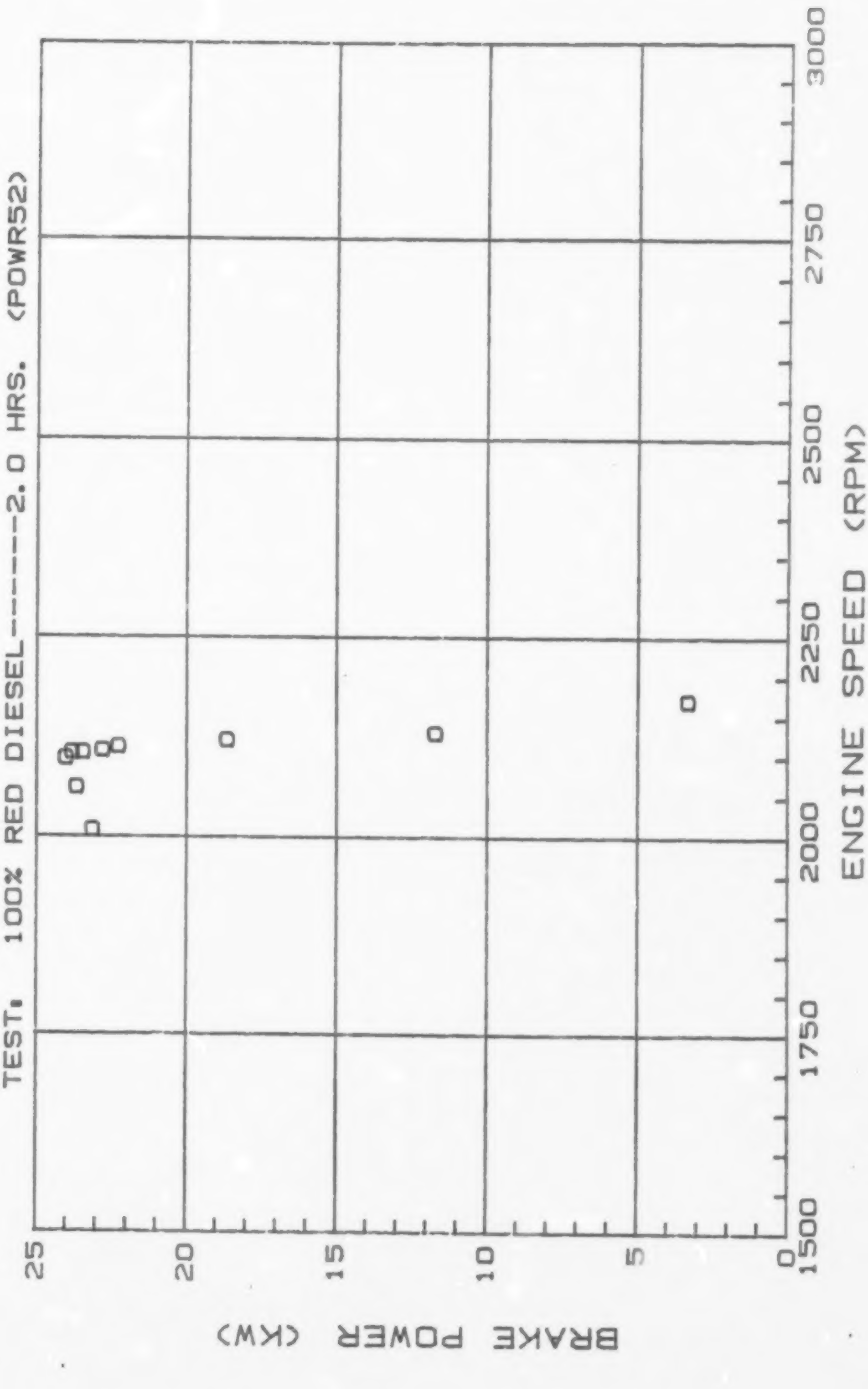
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. MAY 28 .1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. 100% RED DIESEL-------2.0 HRS. (POWR52)



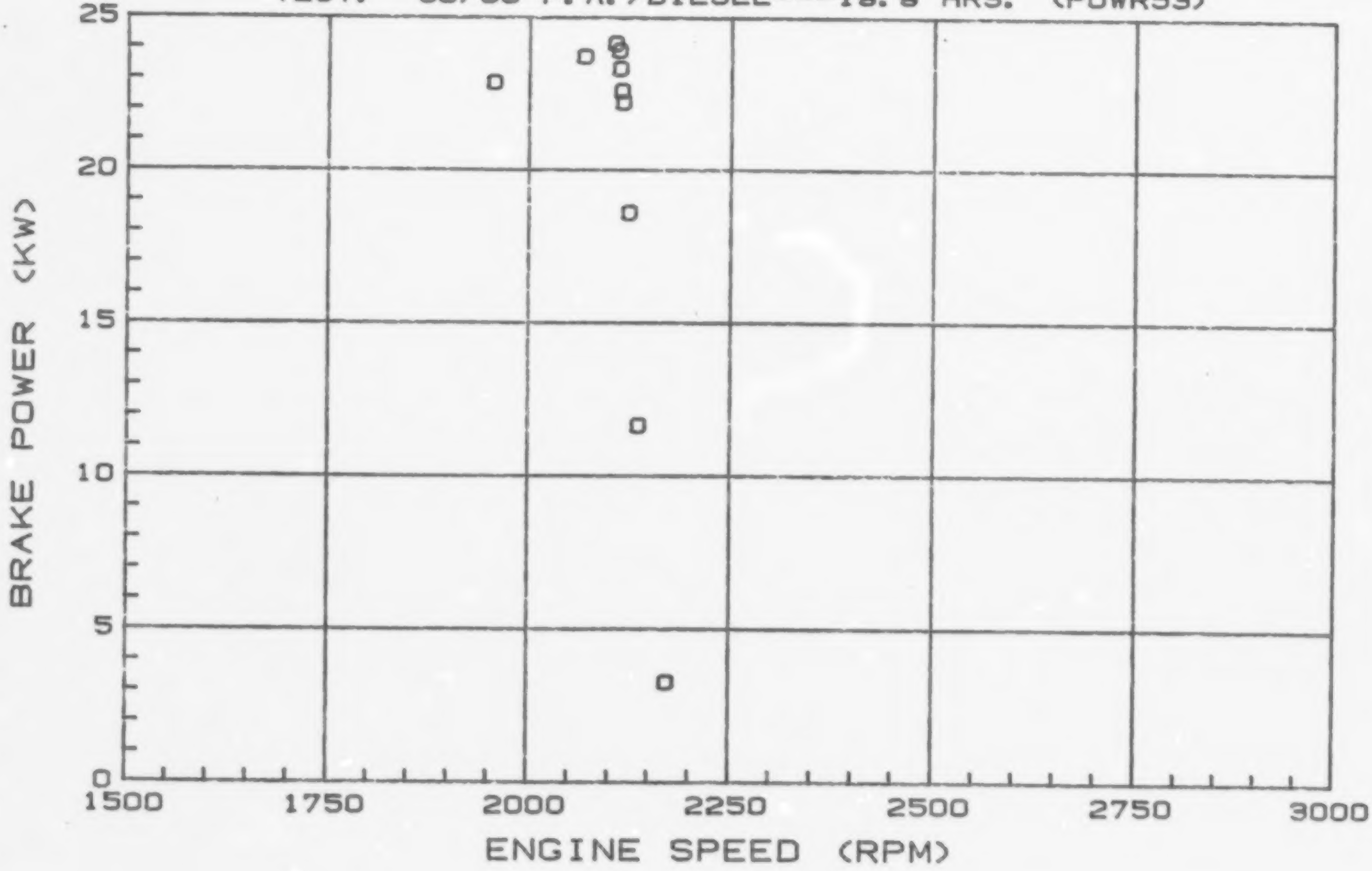
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: MAY 29 . 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50/50 F. A. /DIESEL---19.9 HRS. (POWR53)



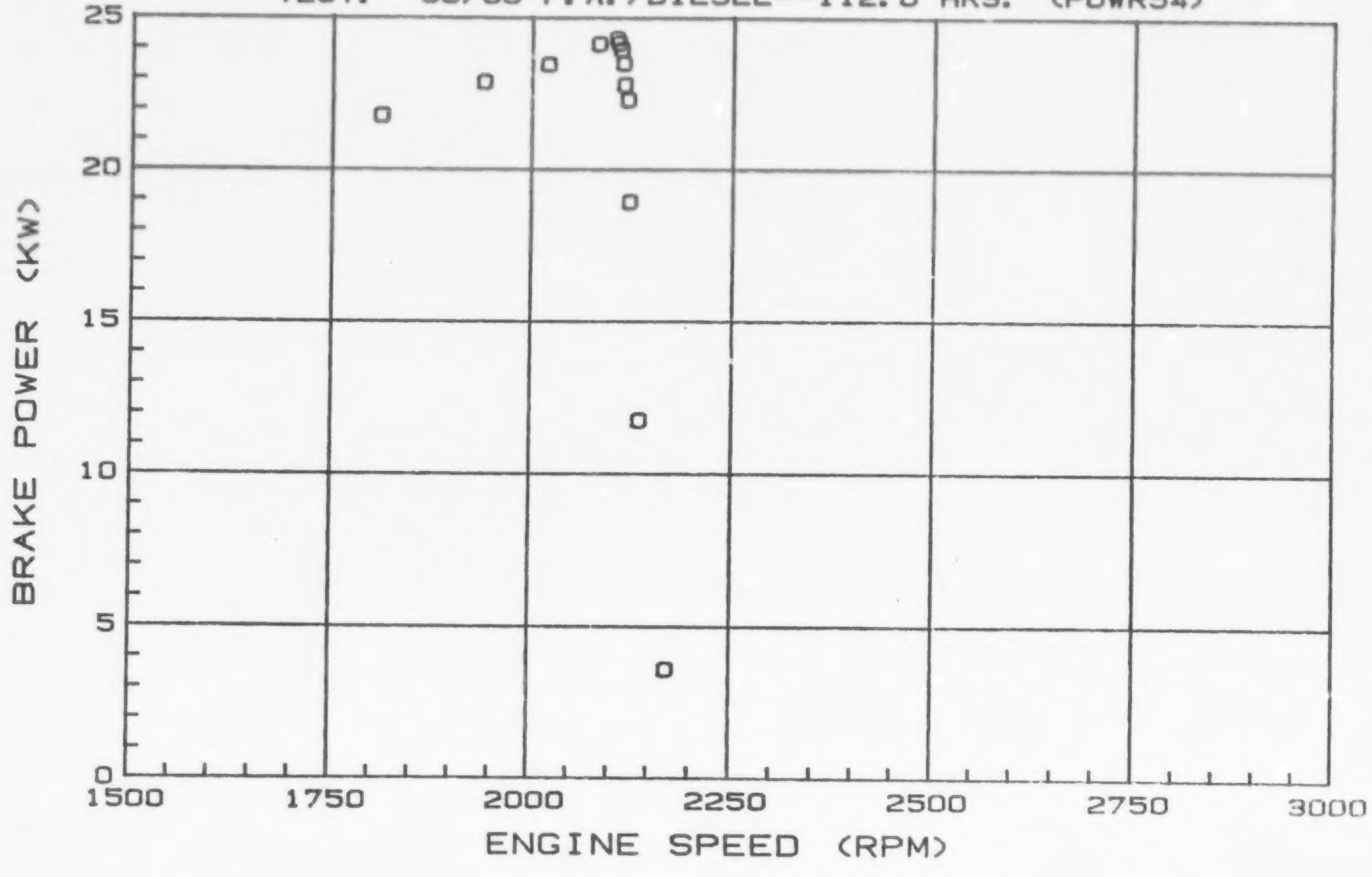
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: JUNE 4, 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50/50 F.A./DIESEL--112.0 HRS. (POWR54)



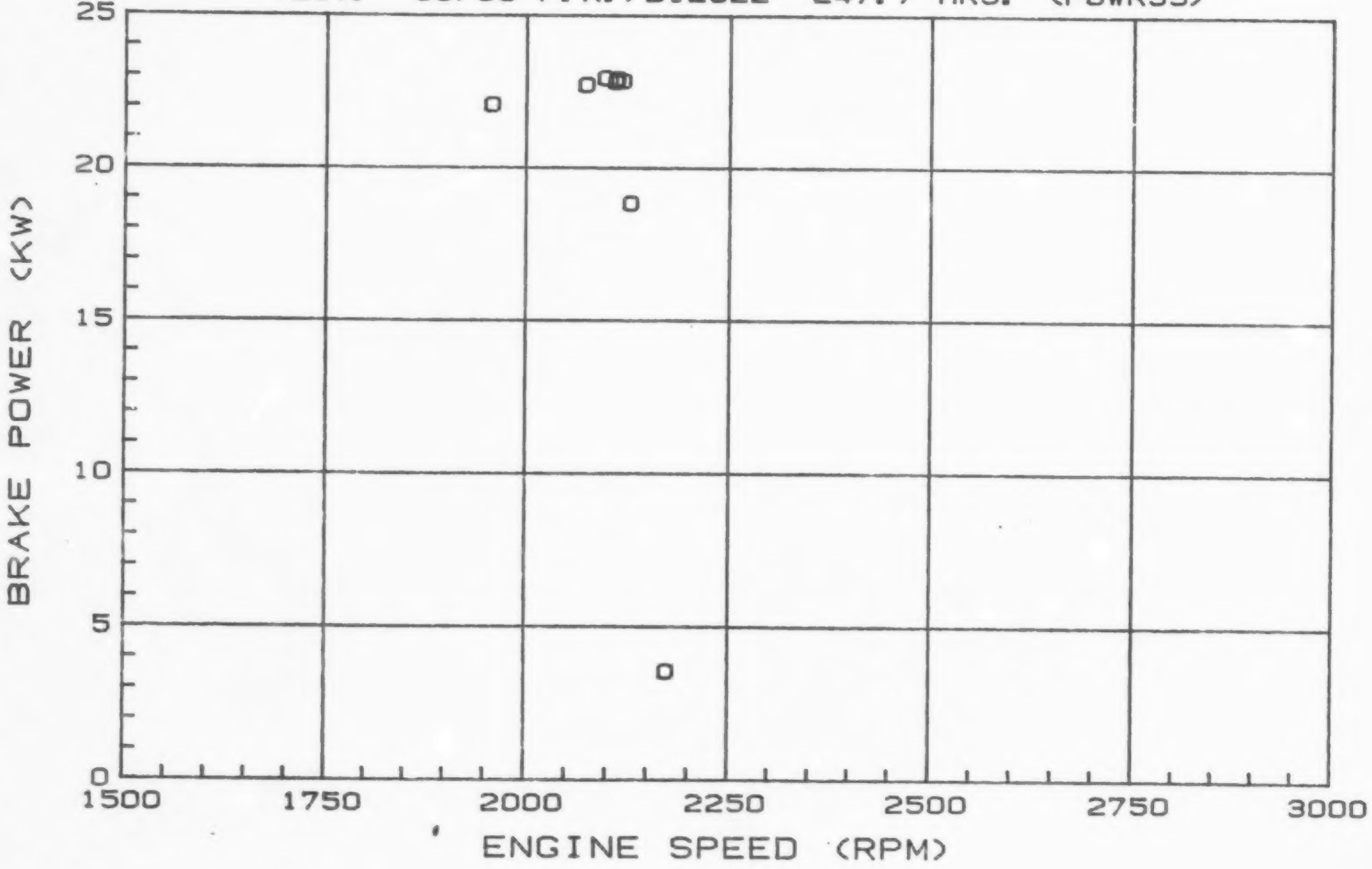
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. JUNE 14. 1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. 50/50 F. A. /DIESEL--247. 7 HRS. (POWR55)



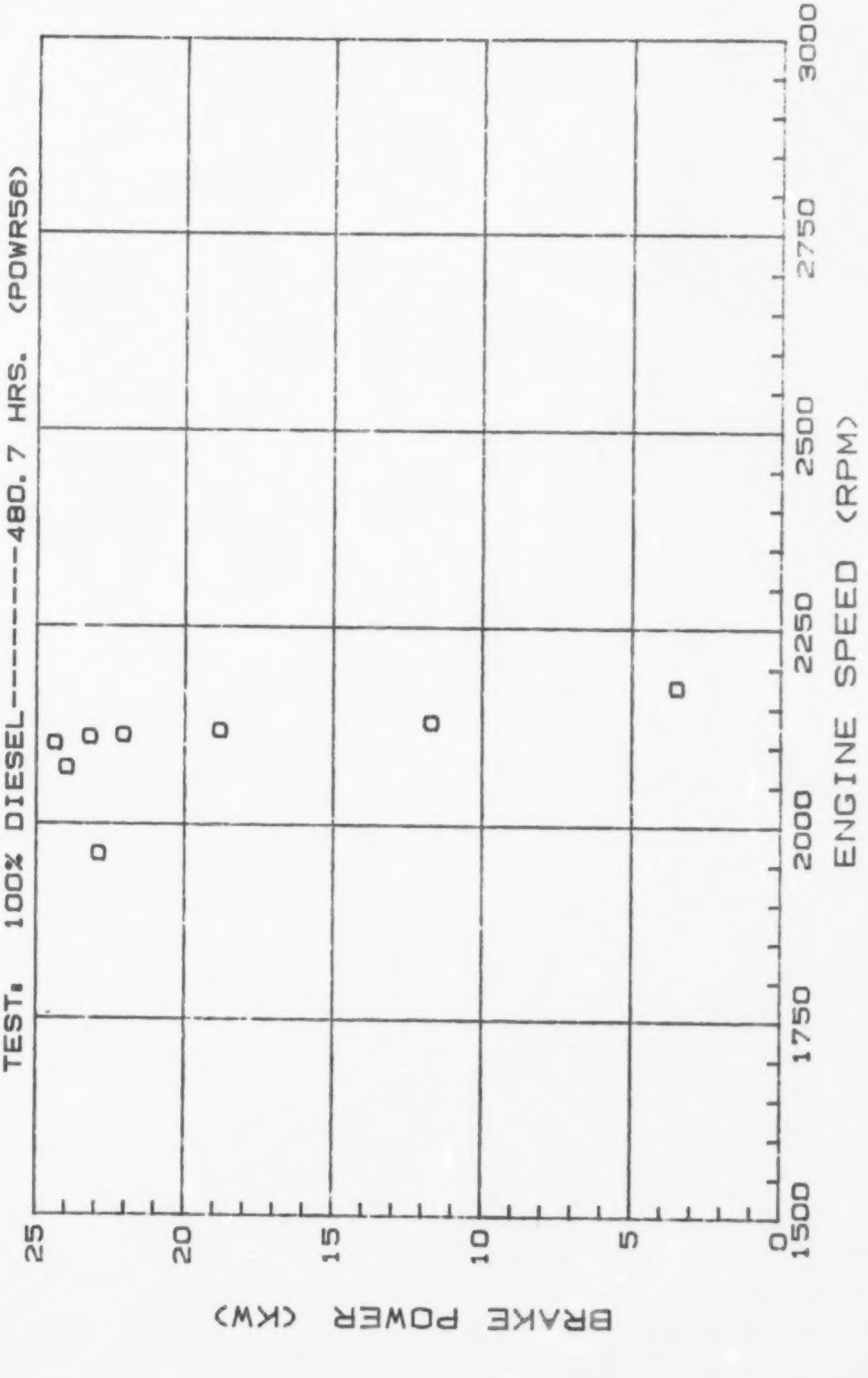
UNIVERSITY OF SASKATCHEWAN–FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. AUG. 1.1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. 100% DIESEL---------480.7 HRS. (POWR56)



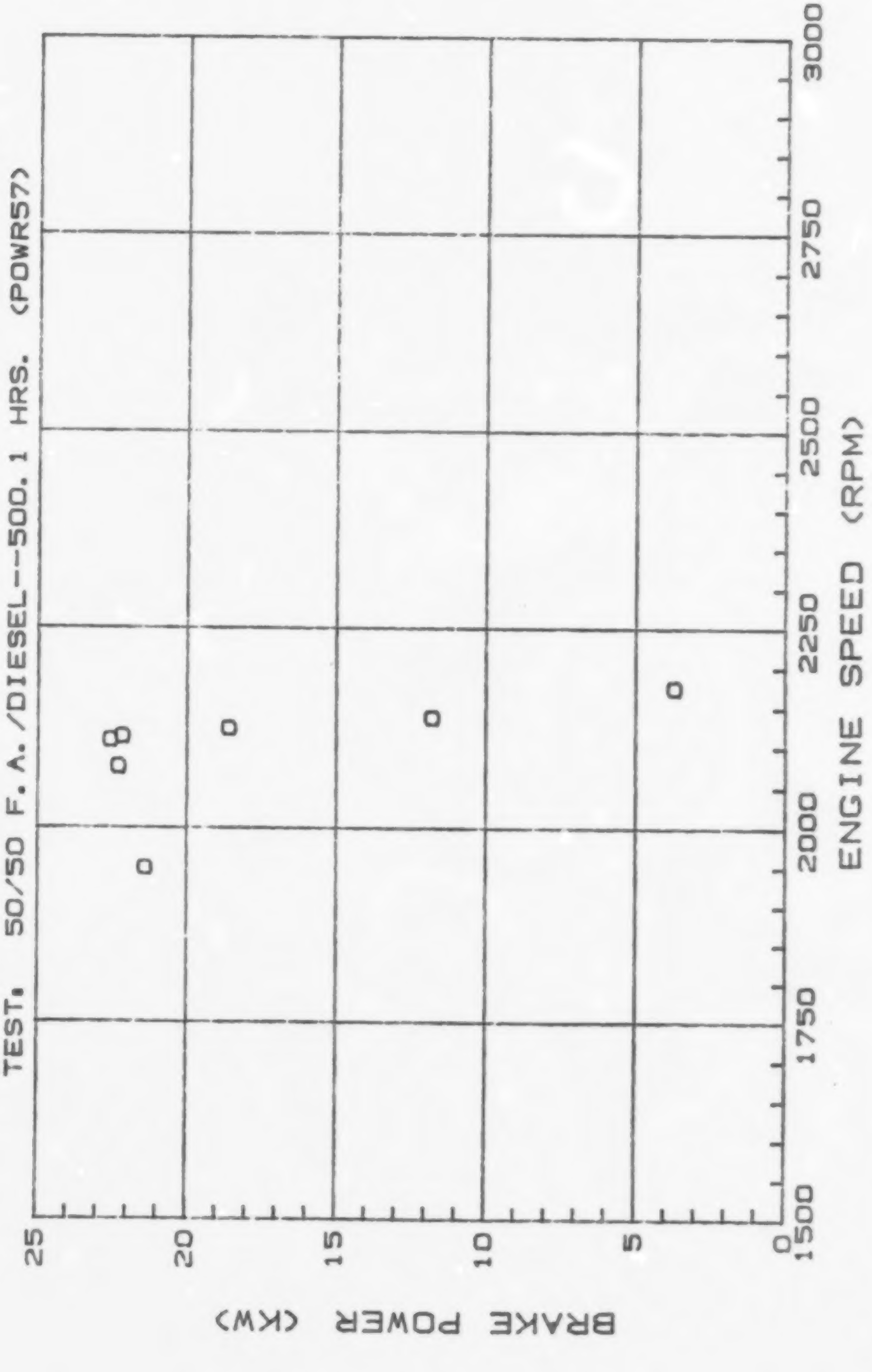
UNIVERSITY OF SASKATCHEWAN--FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. AUG. 2.1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. 50/50 F.A./DIESEL--500.1 HRS. (POWR57)



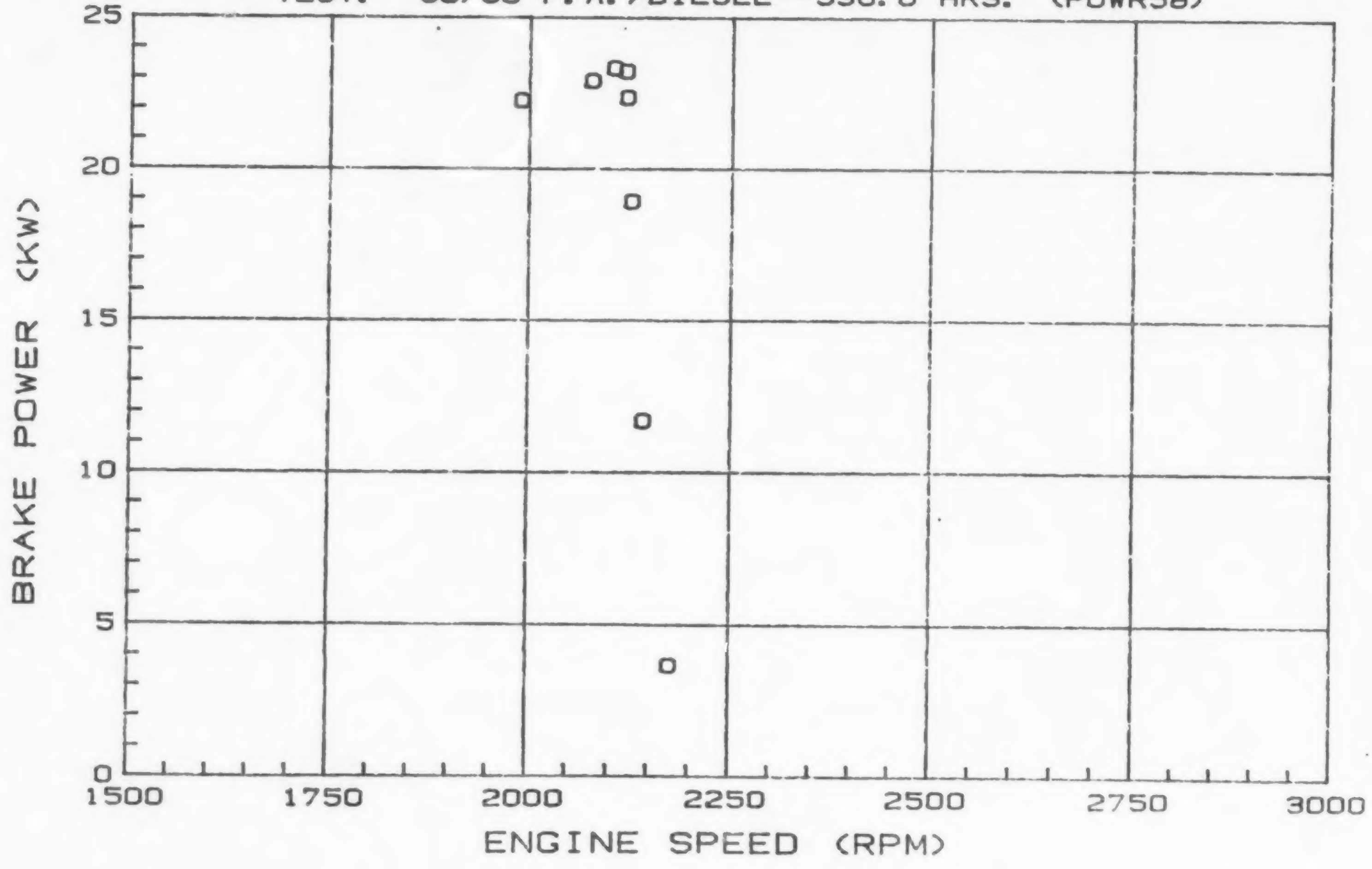
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

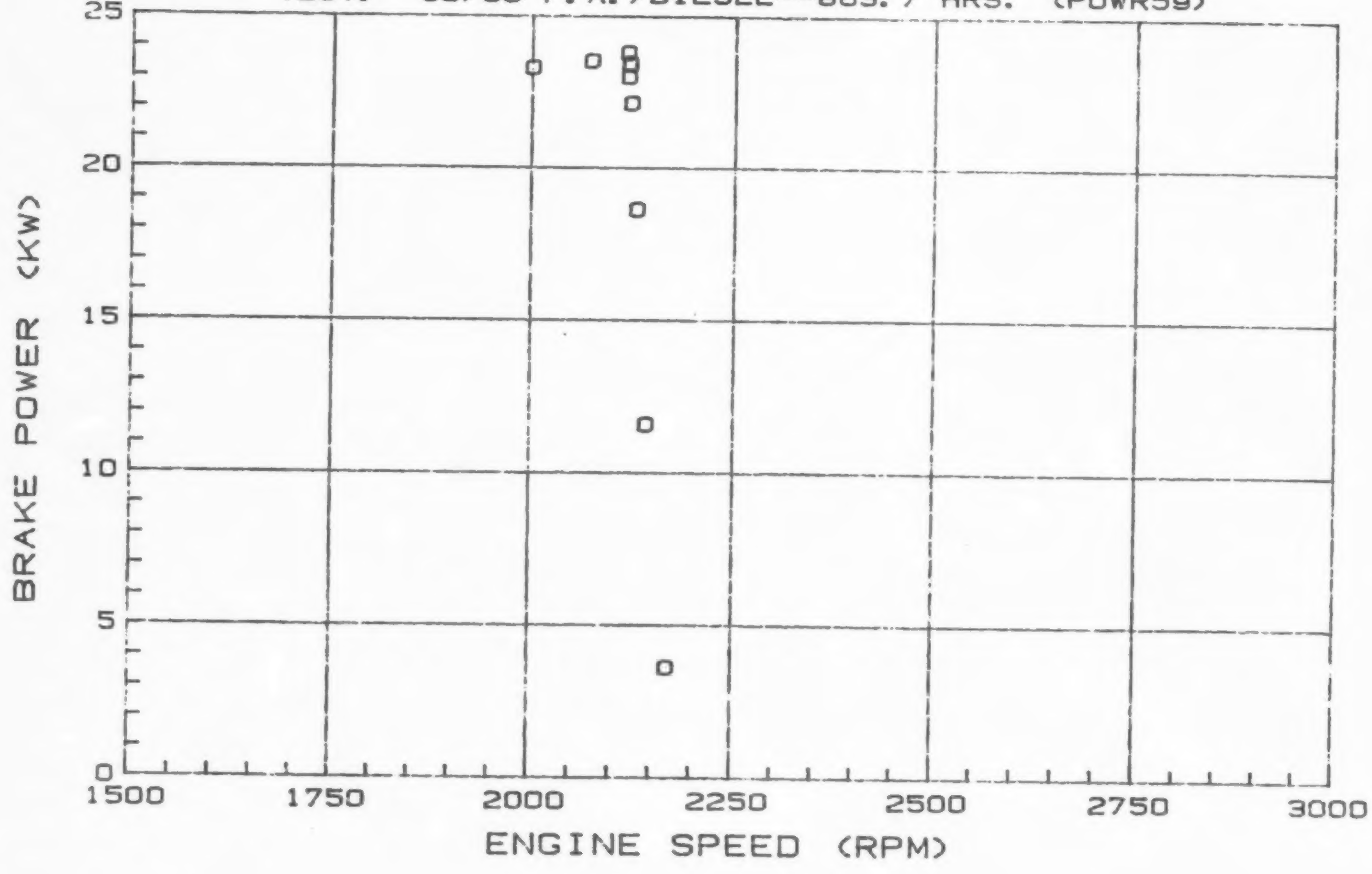
DATE. AUG. 7, 1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. 50/50 F. A. /DIESEL--536. 0 HRS. (POWR58)



UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.
DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*
DATE: AUG. 26, 1985--ENGINE: DEUTZ F2L912 2 CYL.
TEST: 50/50 F.A./DIESEL--863.7 HRS. (POWR59)



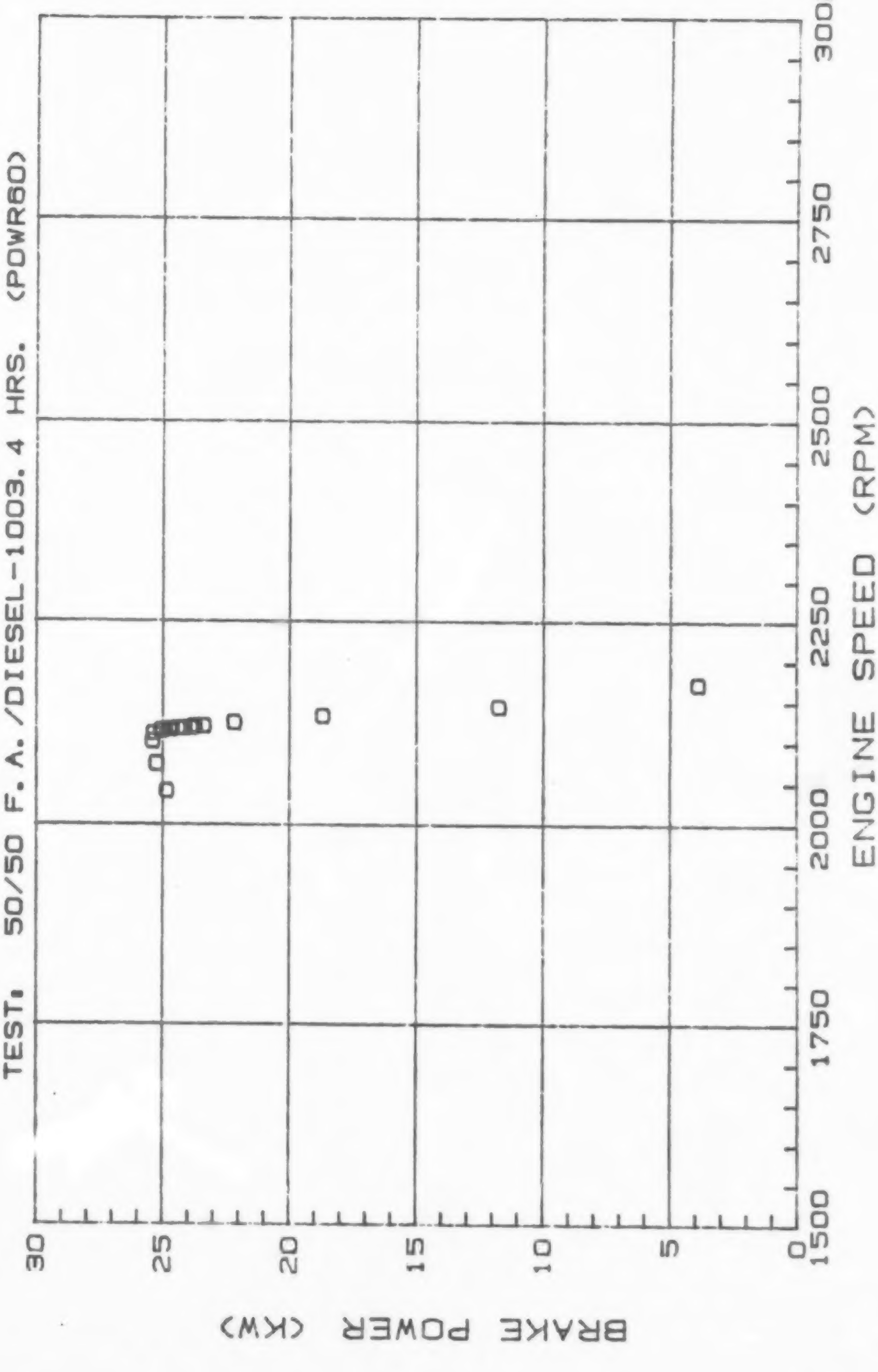
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

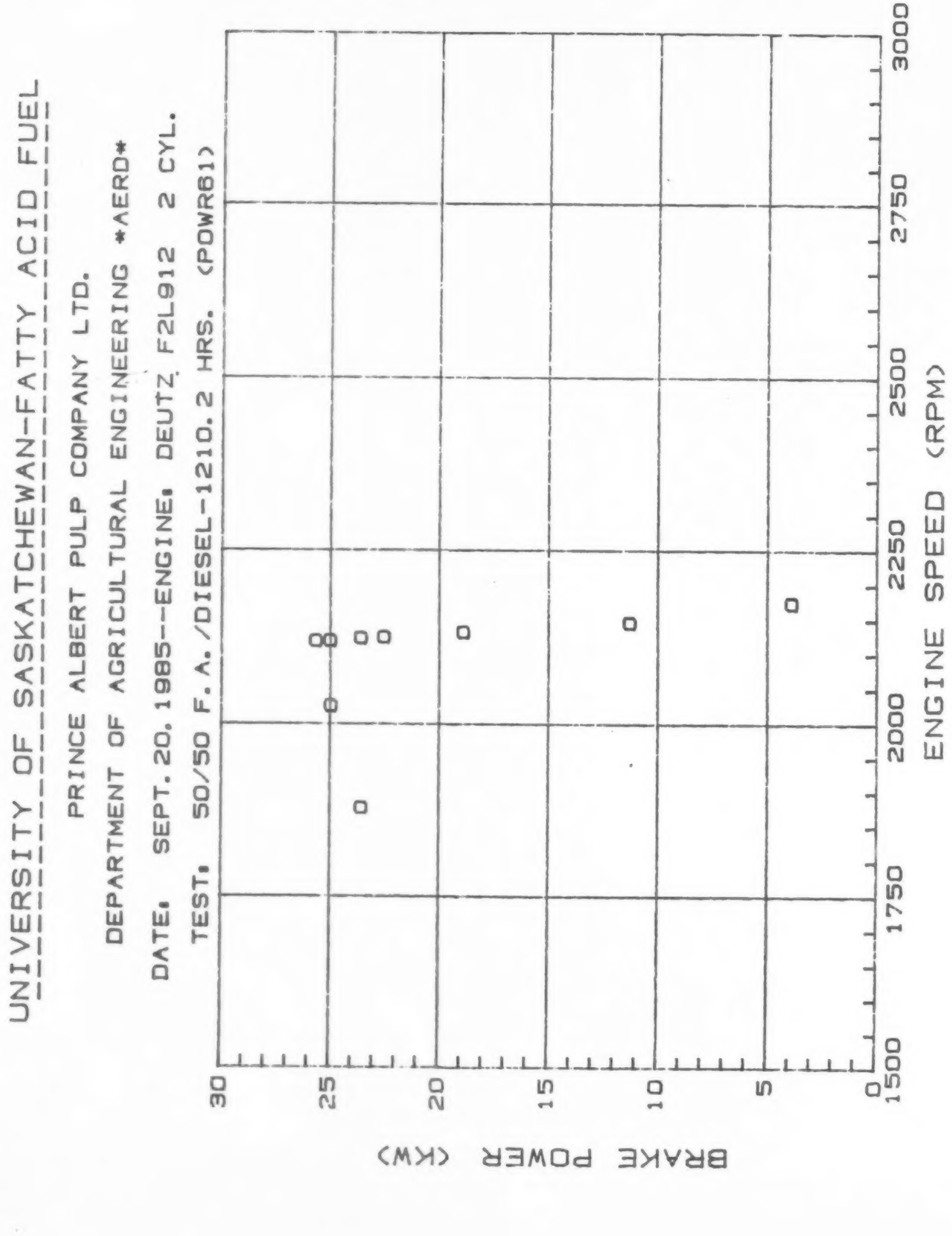
PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. SEPT. 9, 1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. 50/50 F.A./DIESEL-1003.4 HRS. (POWR60)





UNIVERSITY OF SASKATCHEWAN–FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

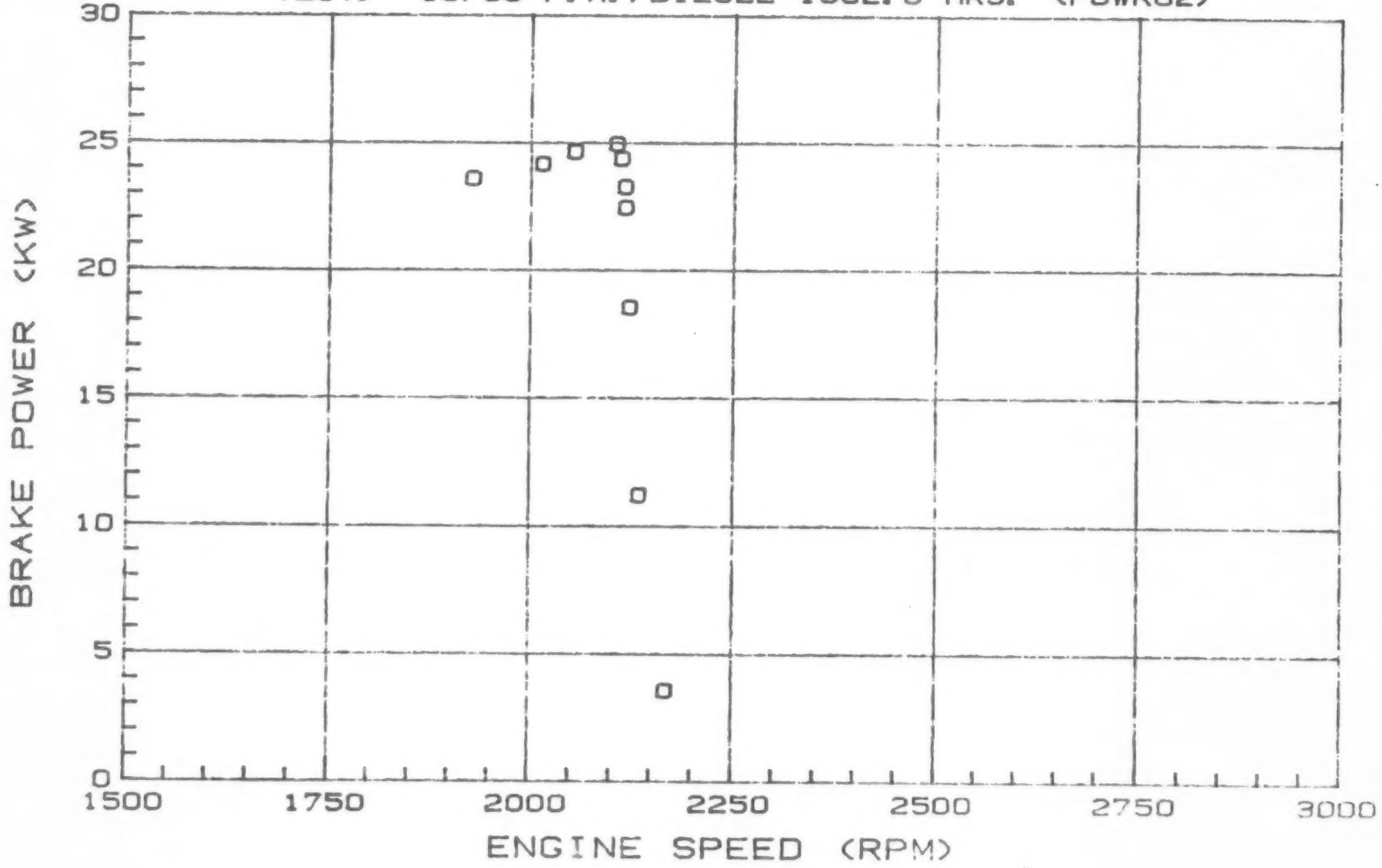
DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. SEPT.20,1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. 50/50 F.A./DIESEL-1210.2 HRS. (POWR61)

UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.
DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*
DATE: OCT. 02. 1985--ENGINE: DEUTZ F2L912 2 CYL.
TEST: 50/50 F. A. /DIESEL-1362. 8 HRS. (POWR62)



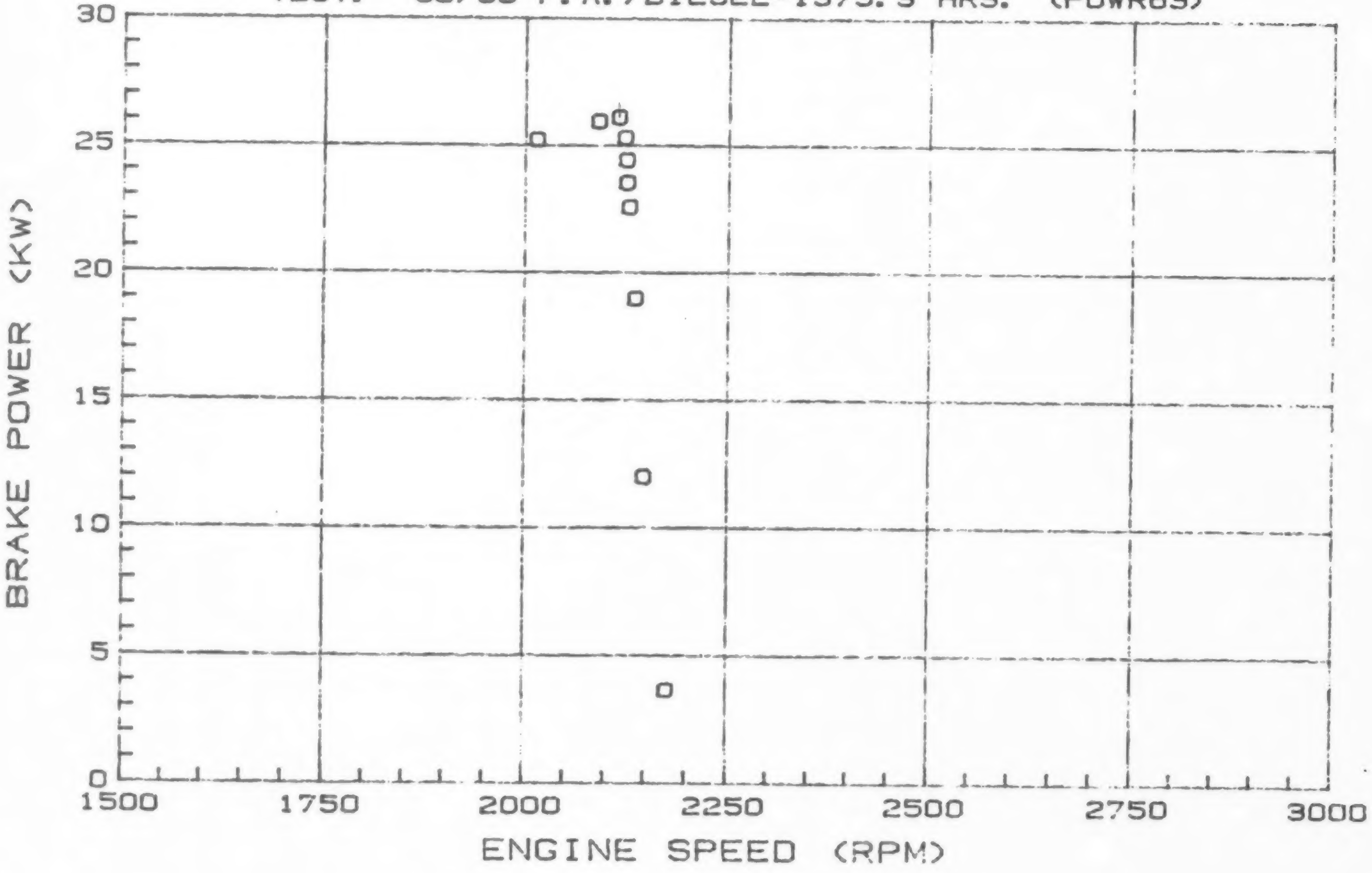
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: OCT. 07. 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50/50 F. A. /DIESEL-1375. 3 HRS. (POWR63)



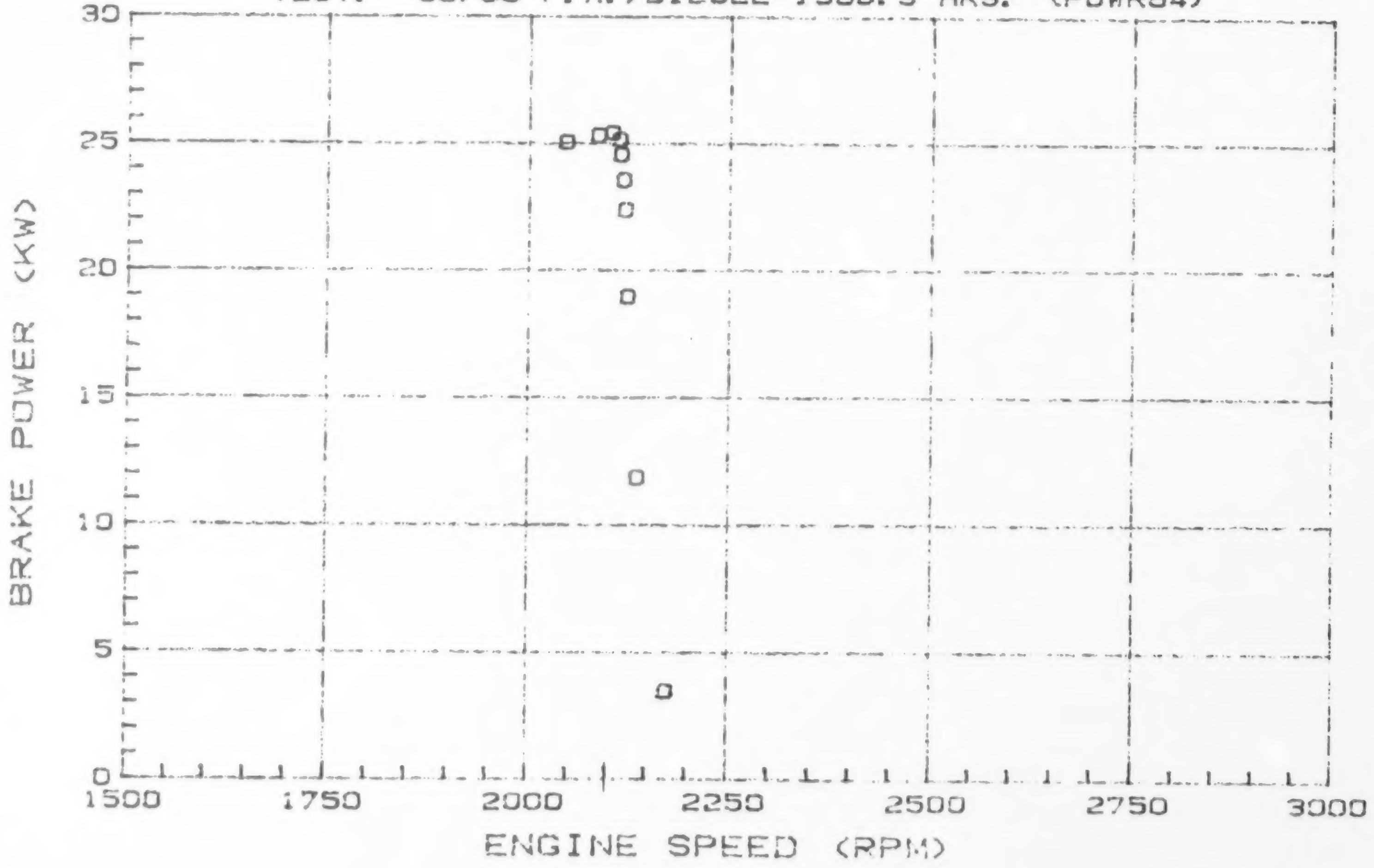
UNIVERSITY OF SASKATCHEWAN–FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: OCT. 28, 1985---ENGINE: DEUTZ F2L912 2 CYL.

TEST: 50/50 F.A./DIESEL-1568.3 HRS. (POWR64)



APPENDIX C

RESULTS OF
LUBRISCAN CRANKCASE OIL ANALYSIS

(Metal Concentrations (ppm) versus Engine Hours)

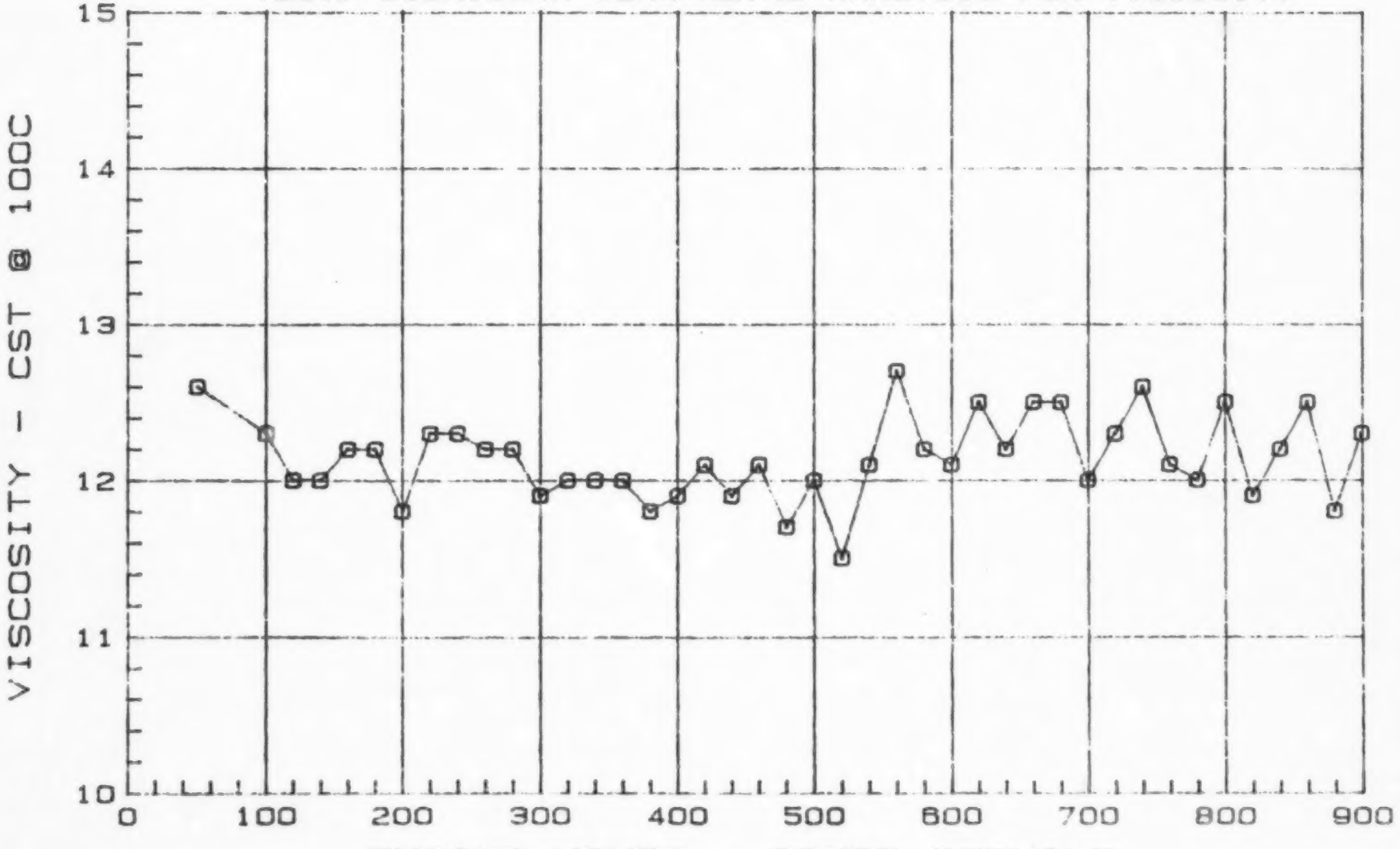
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR VISCOSITY



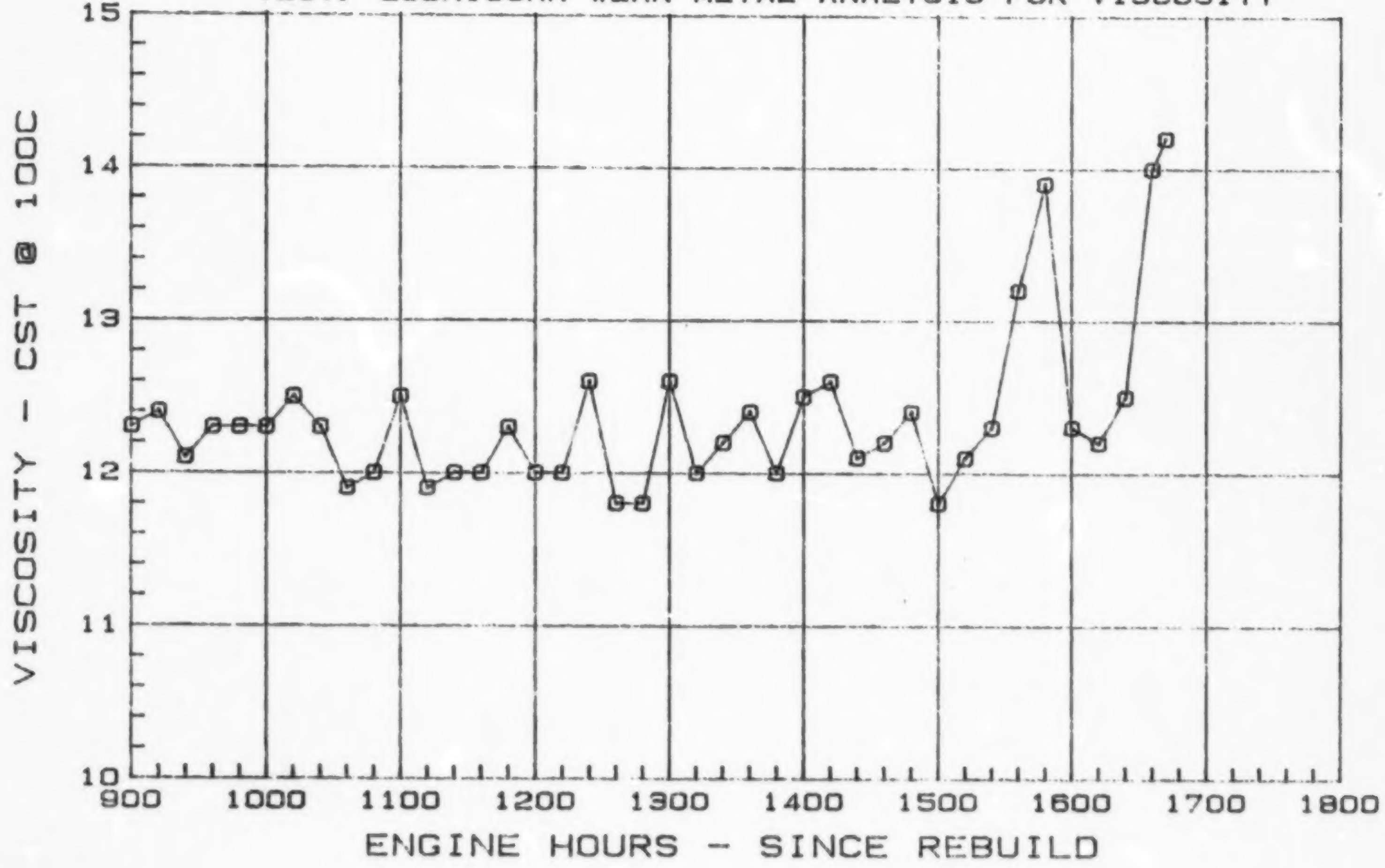
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. DECEMBER, 1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. LUBRISCAN WEAR METAL ANALYSIS FOR VISCOSITY



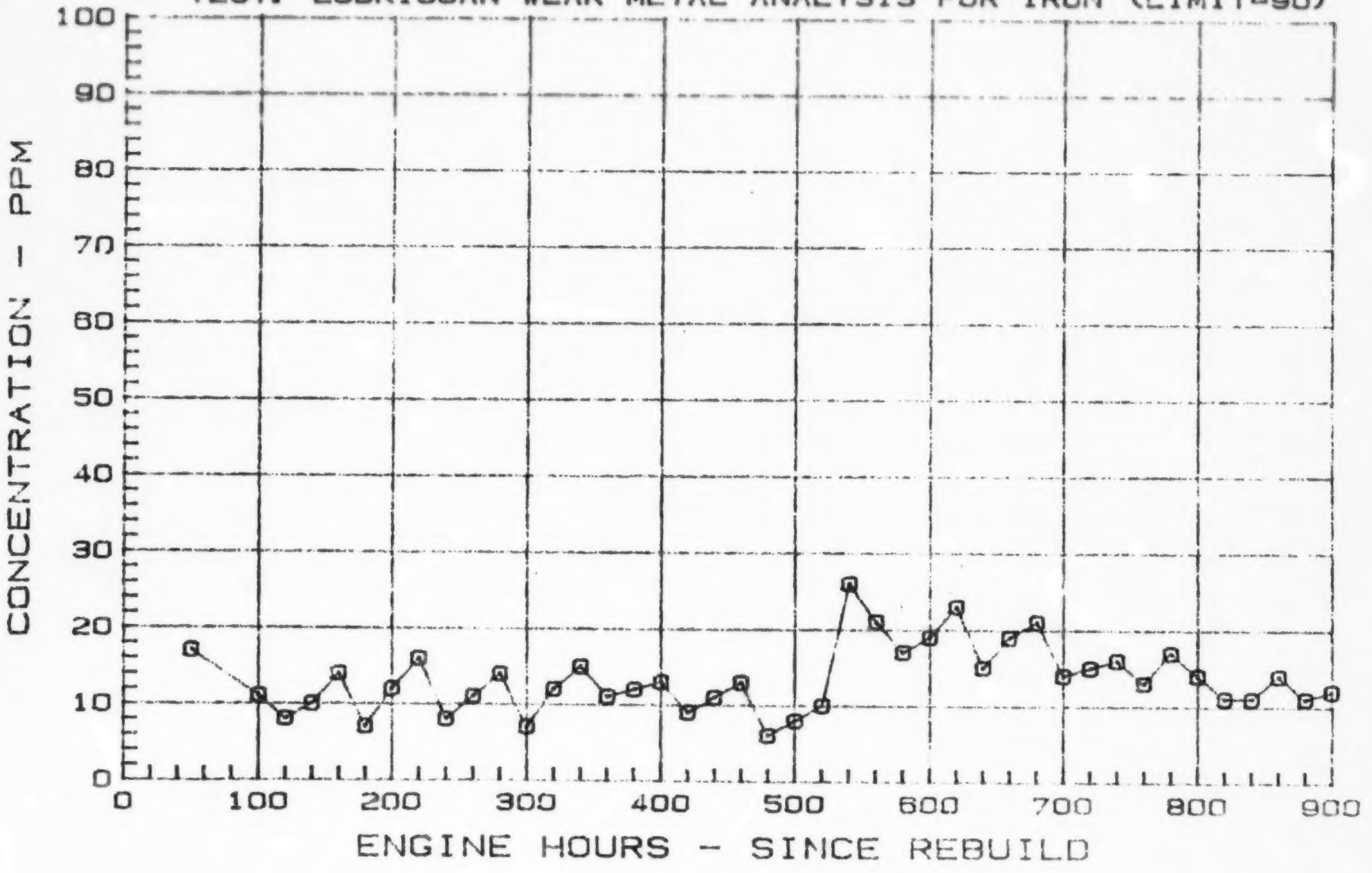
UNIVERSITY OF SASKATCHEWAN--FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR IRON (LIMIT=90)



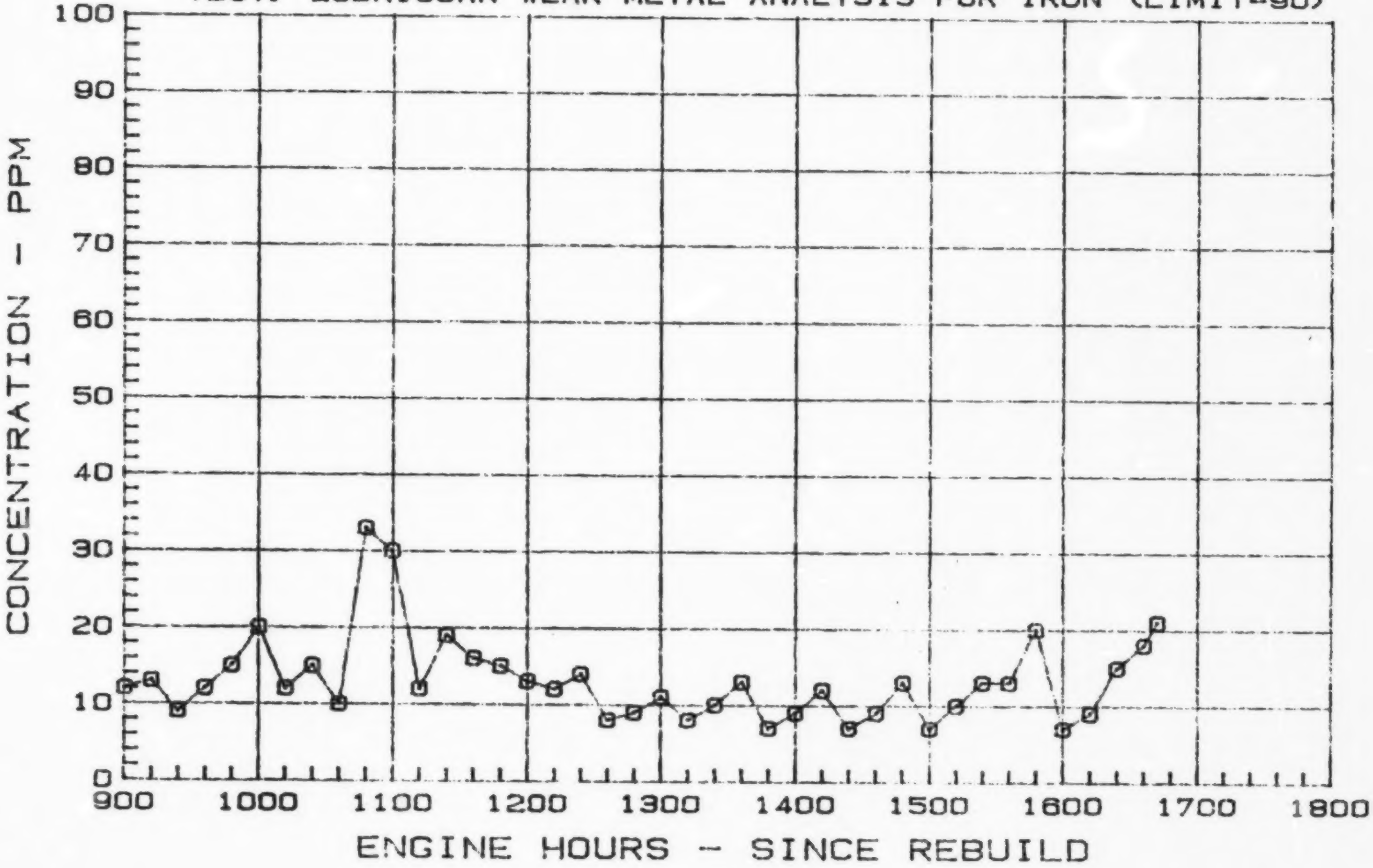
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR IRON (LIMIT=90)



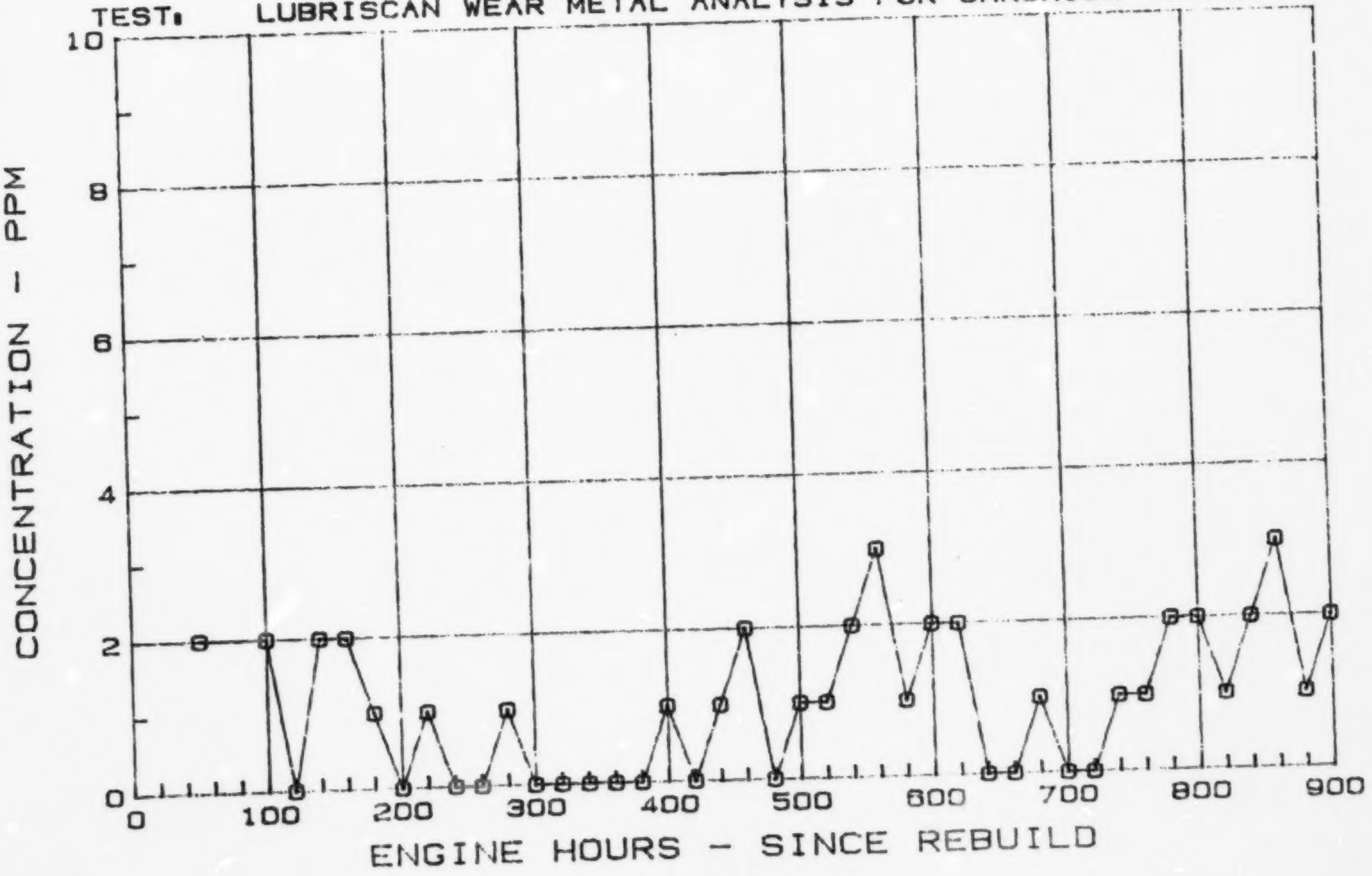
UNIVERSITY OF SASKATCHEWAN–FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR CHROMIUM (LIMIT=10)



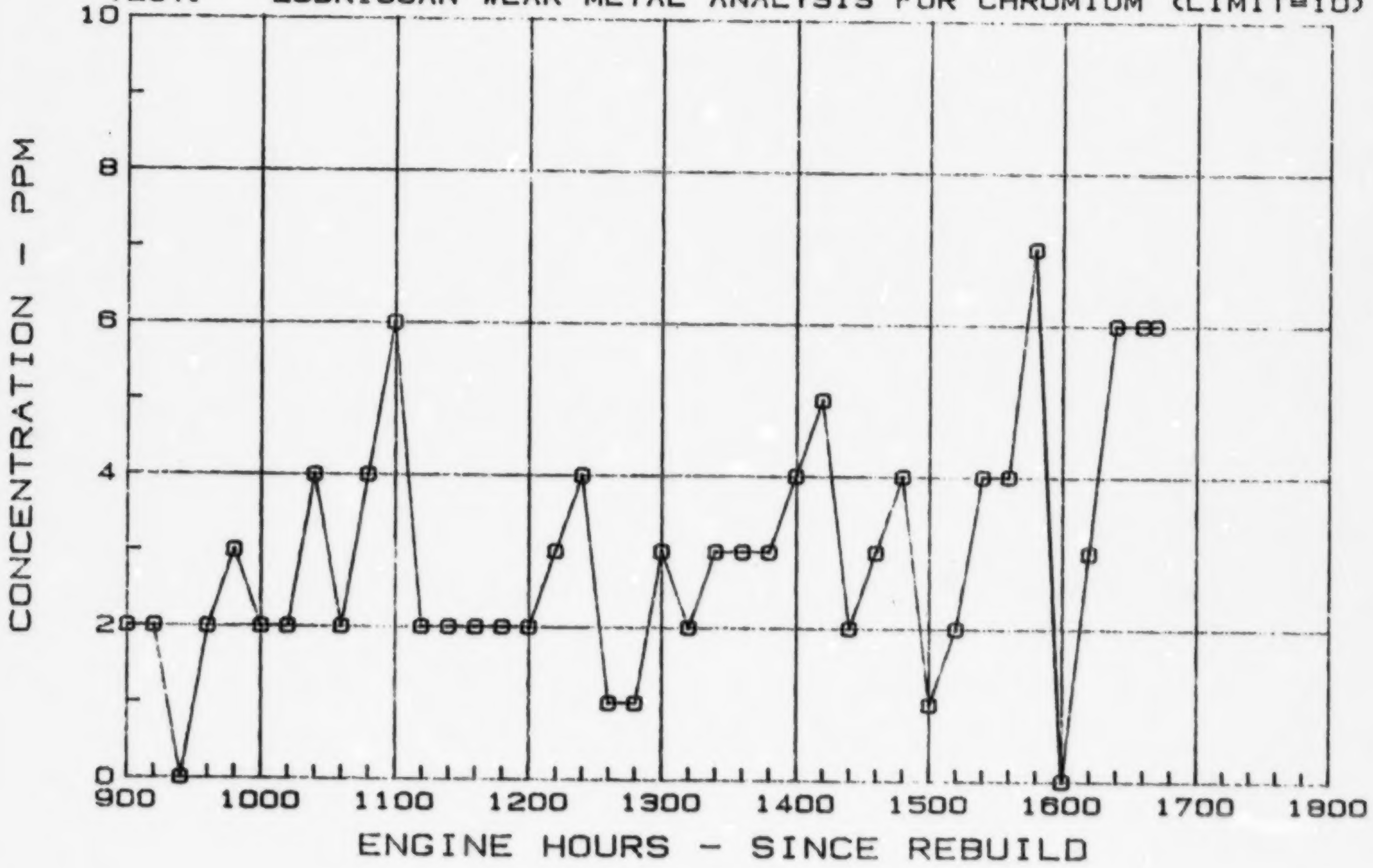
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

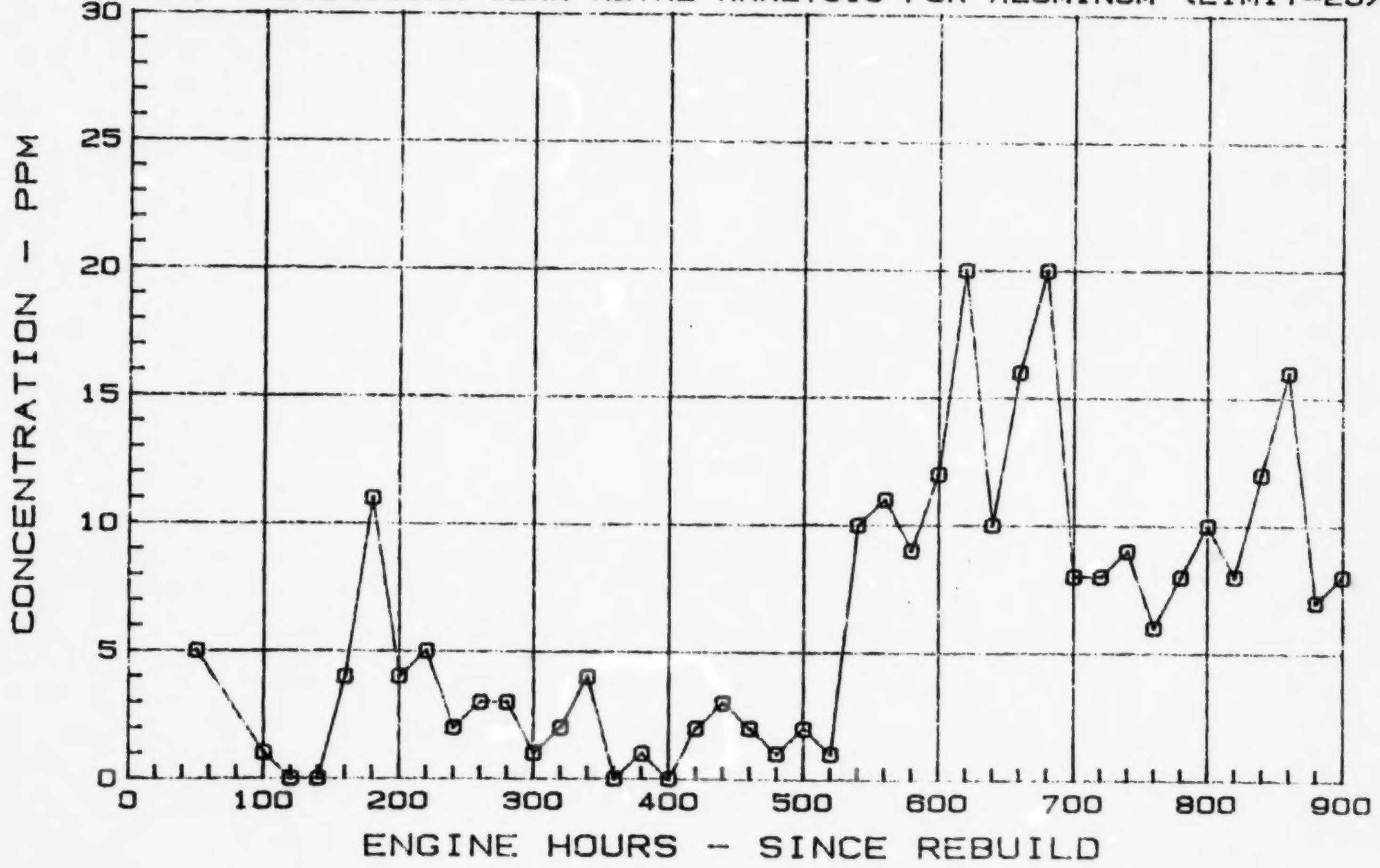
DATE: DECEMBER, 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR CHROMIUM (LIMIT=10)



UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.
DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*
DATE: DECEMBER, 1985--ENGINE: DEUTZ F2L912 2 CYL.
TEST: LUBRISCAN WEAR METAL ANALYSIS FOR ALUMINUM (LIMIT=20)



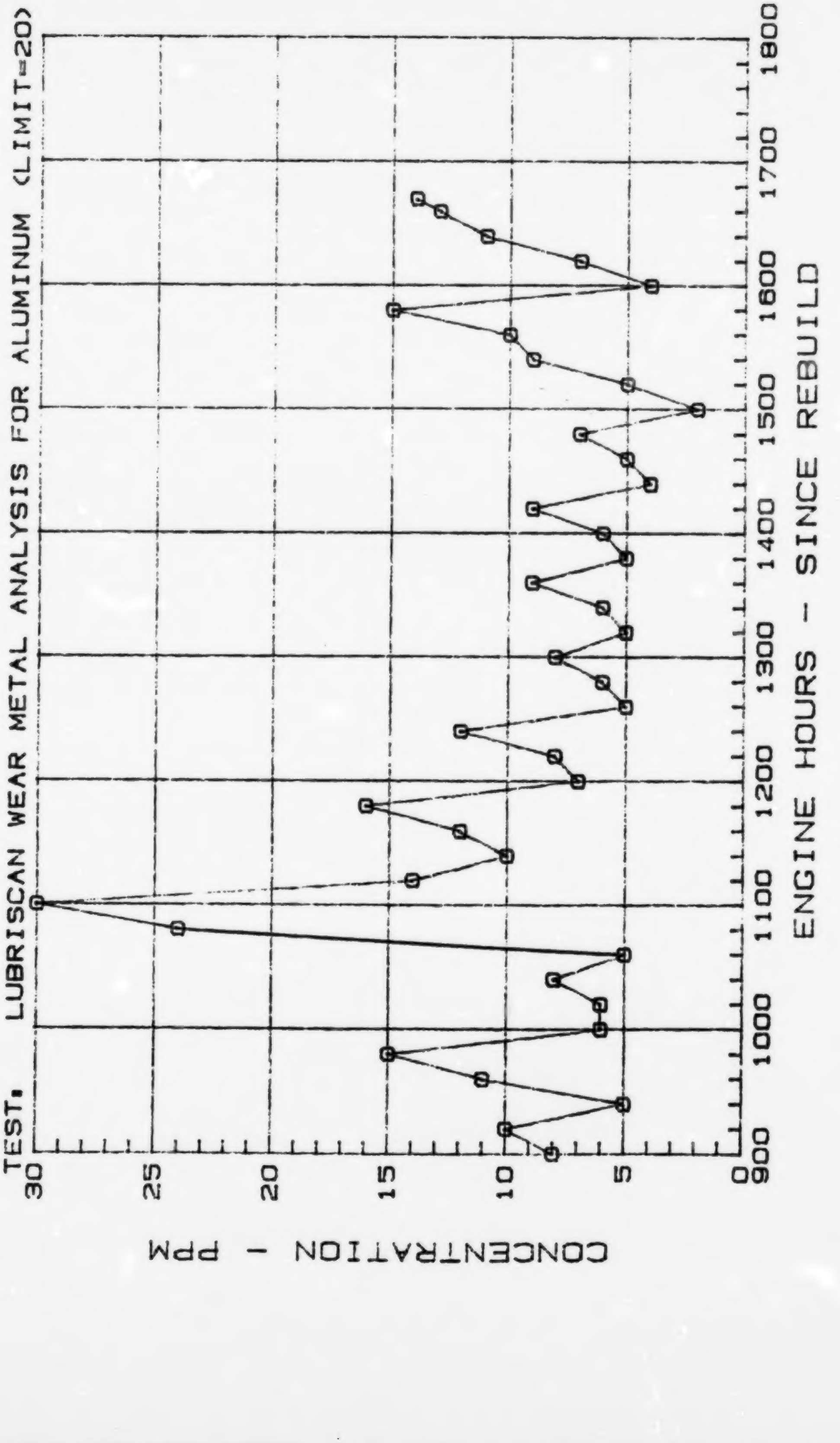
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. DECEMBER, 1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. LUBRISCAN WEAR METAL ANALYSIS FOR ALUMINUM (LIMIT=20)



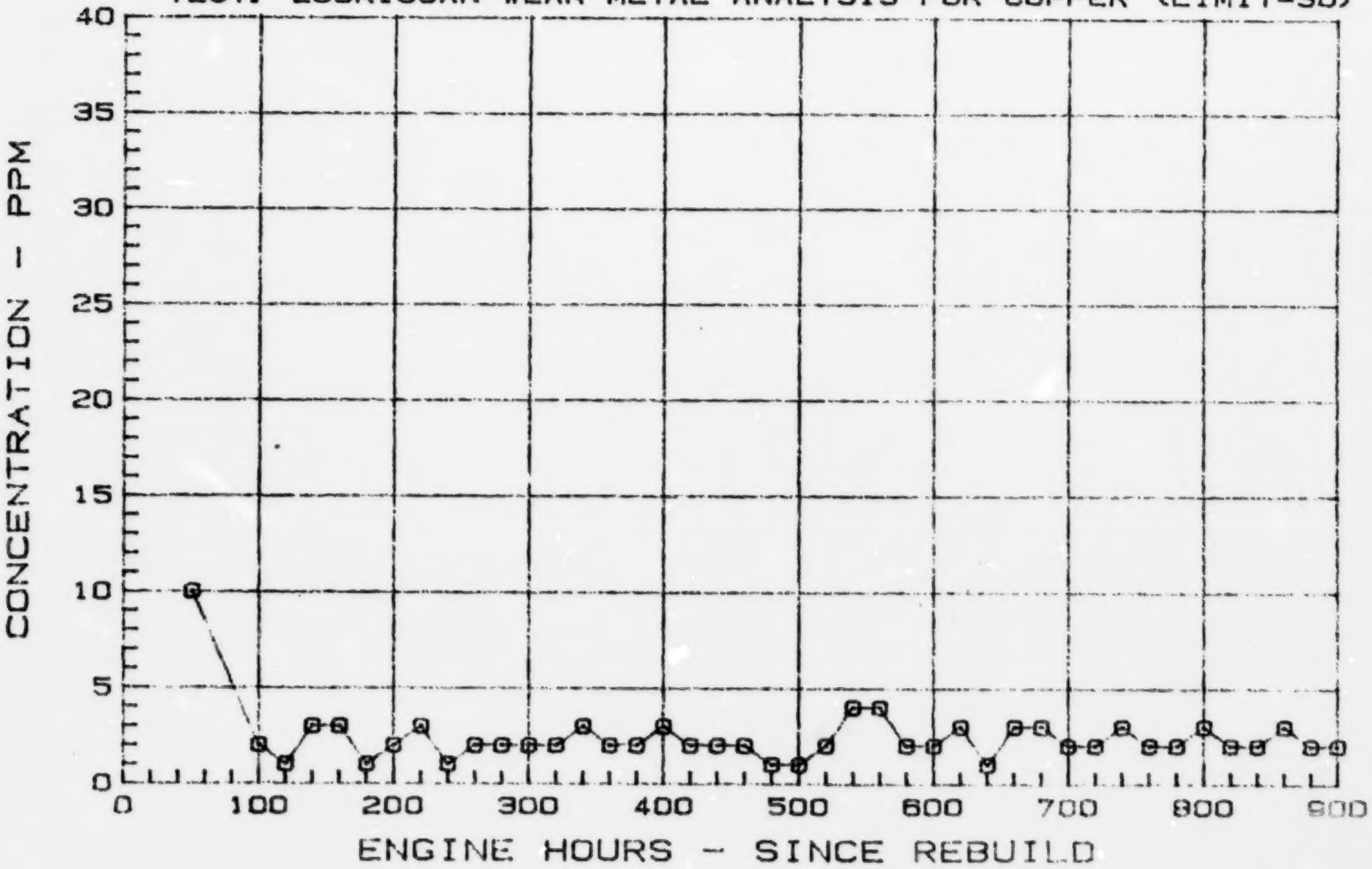
UNIVERSITY OF SASKATCHEWAN–FATTY ACID FUEL

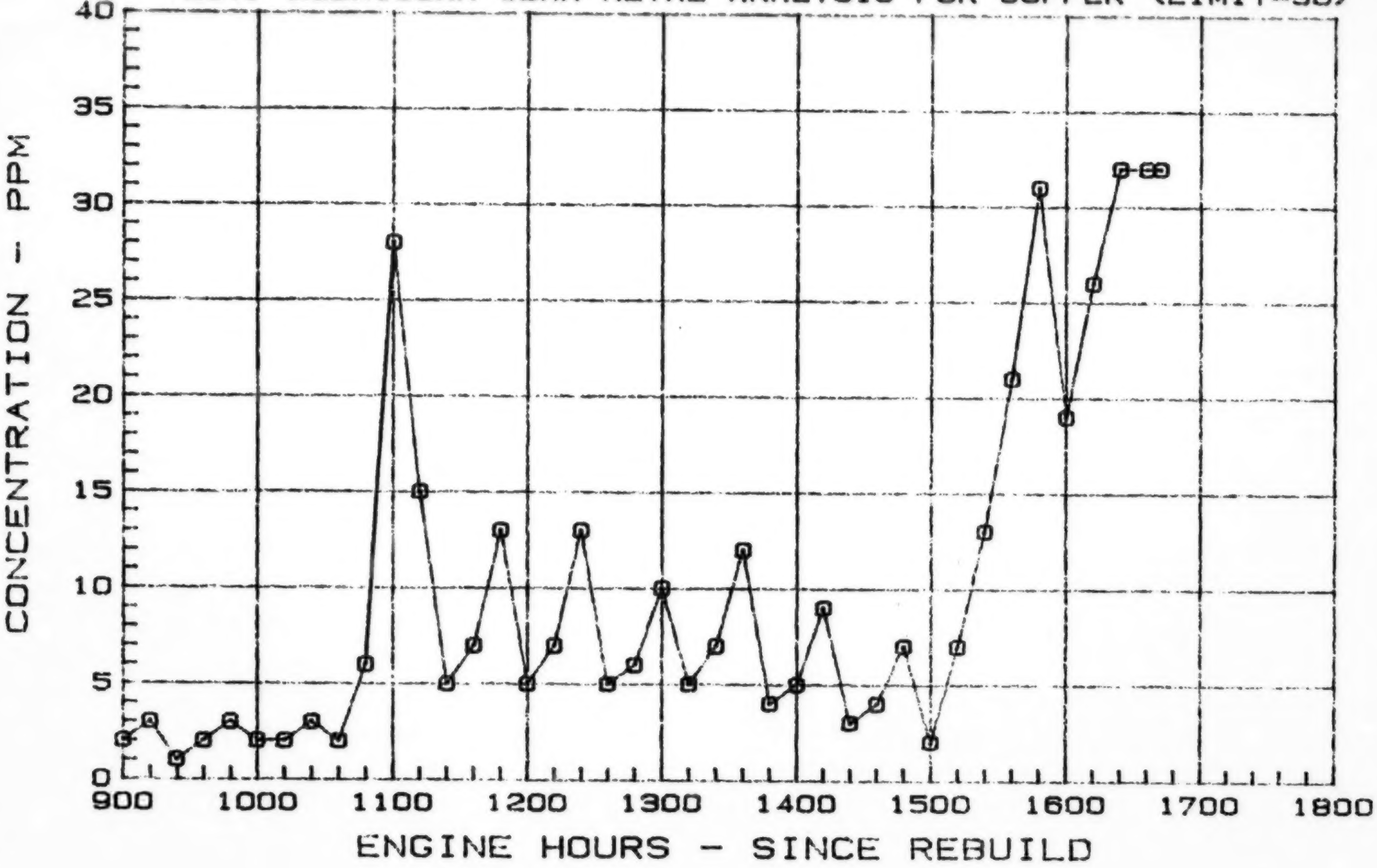
PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. DECEMBER, 1985--ENGINE. DEUTZ·F2L912 2 CYL.

TEST. LUBRISCAN WEAR METAL ANALYSIS FOR COPPER (LIMIT=30)





UNIVERSITY OF SASKATCHEWAN–FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER. 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR COPPER (LIMIT=30)

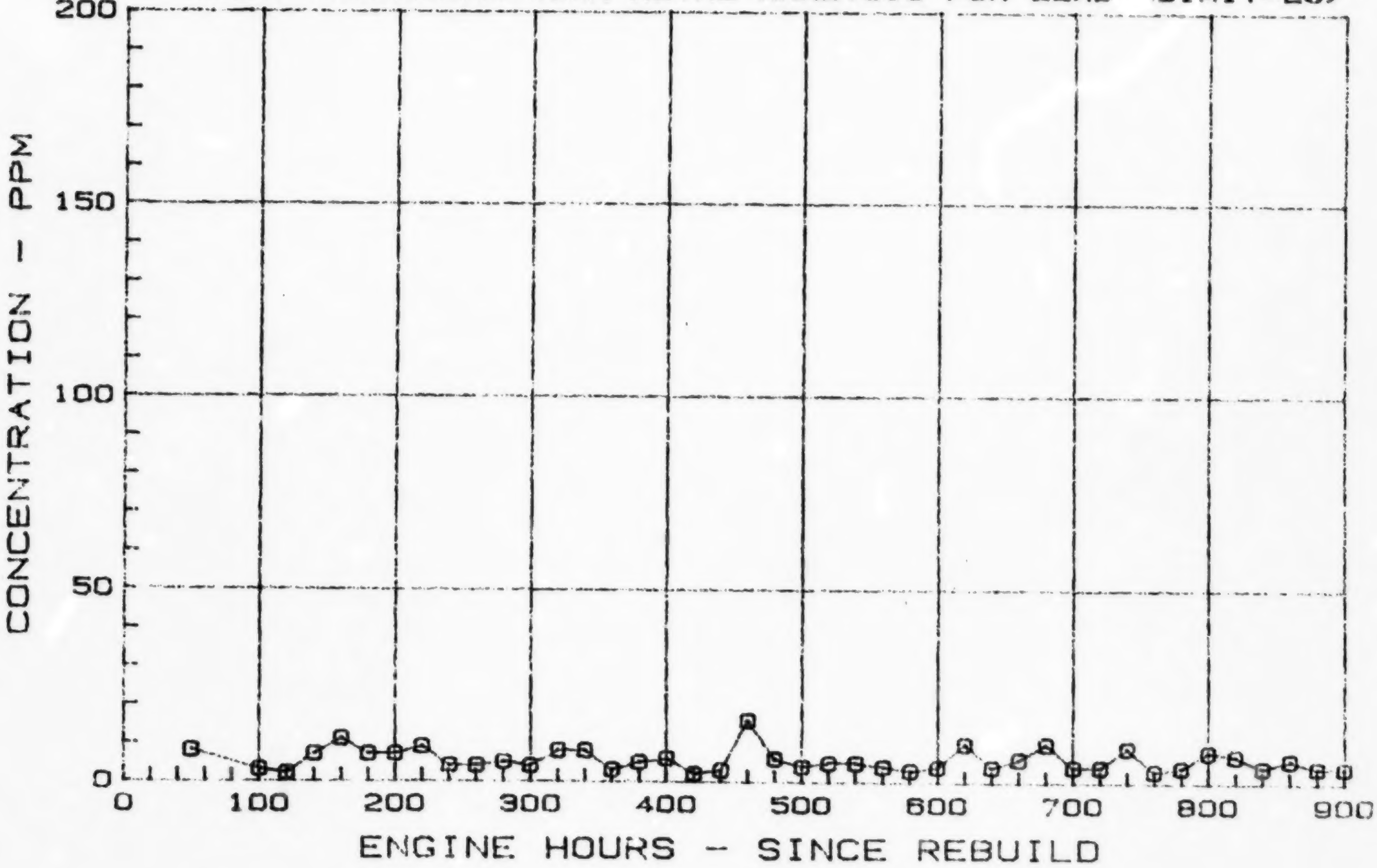
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR LEAD (LIMIT=20)



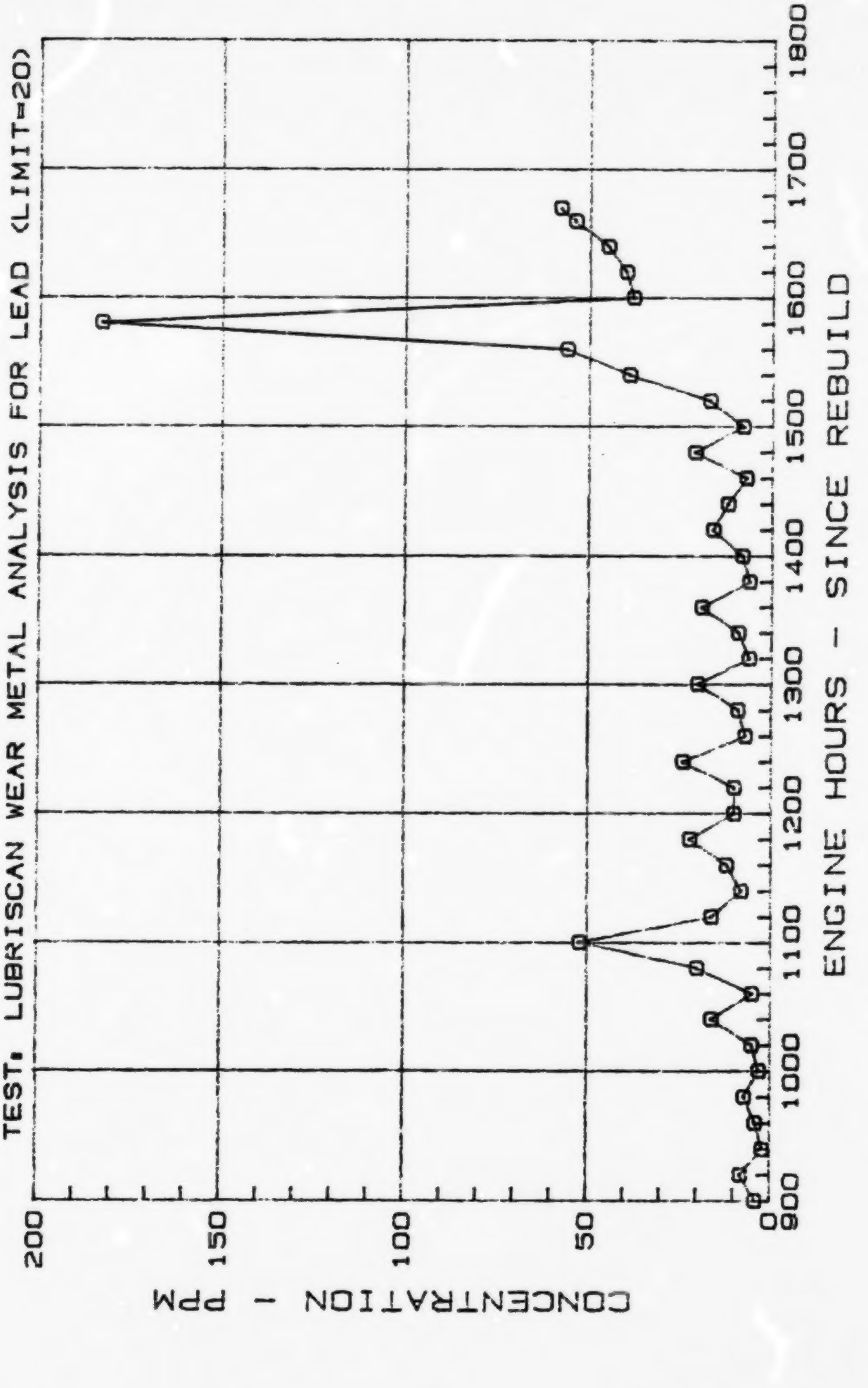
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. DECEMBER, 1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. LUBRISCAN WEAR METAL ANALYSIS FOR LEAD (LIMIT=20)



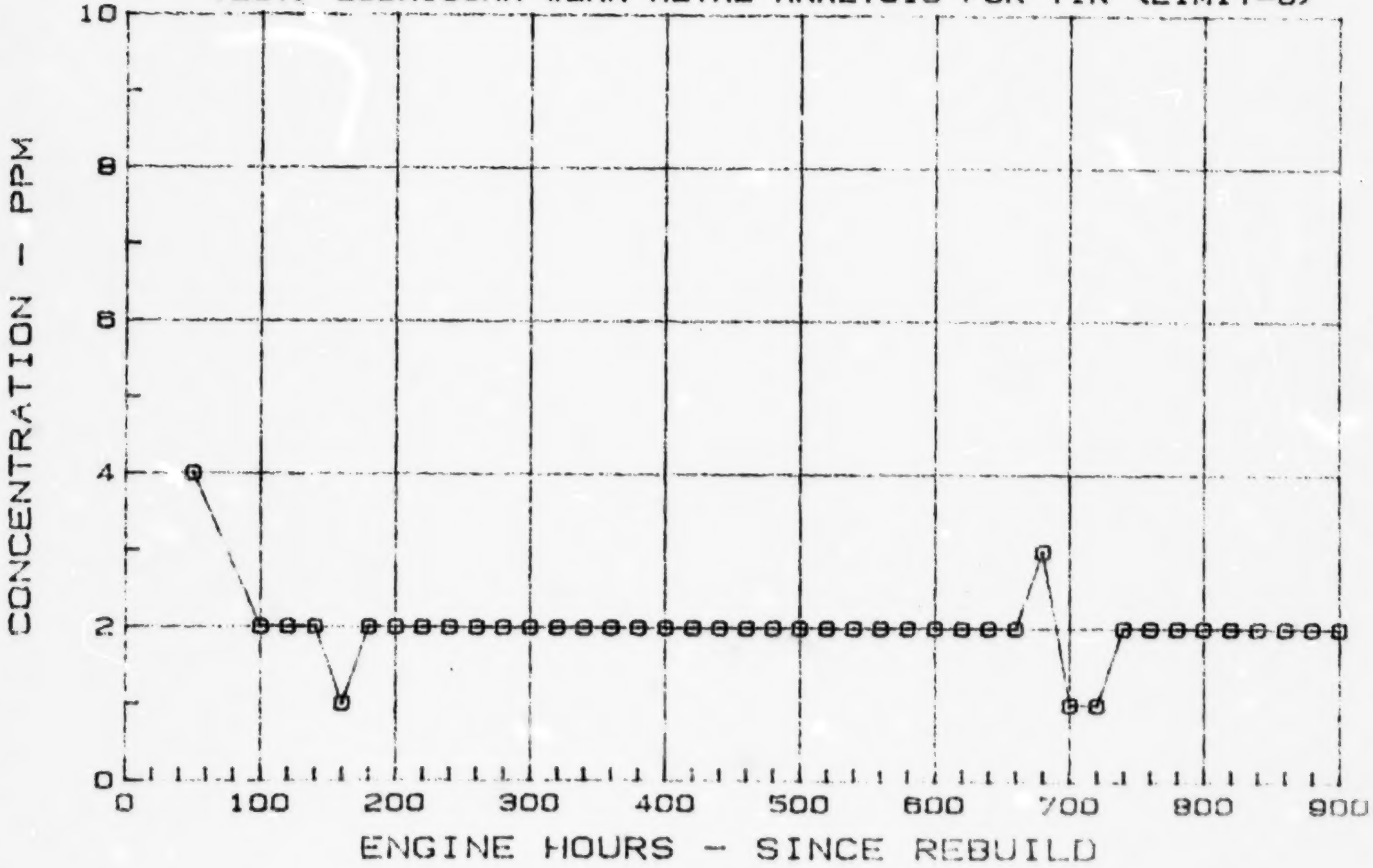
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. DECEMBER. 1985--ENGINE. DEUTZ. F2L912 2 CYL.

TEST. LUBRISCAN WEAR METAL ANALYSIS FOR TIN (LIMIT=8)



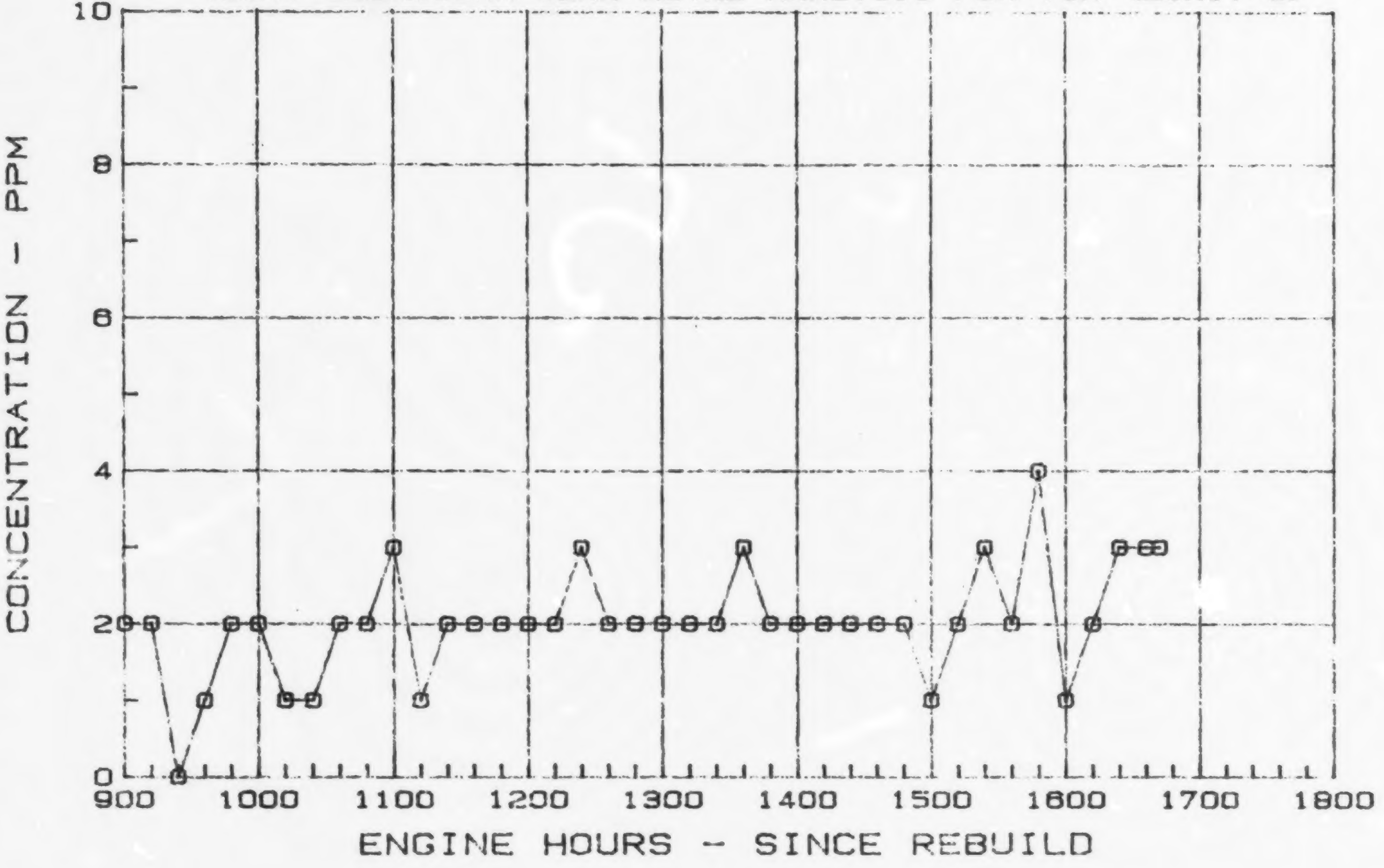
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR TIN (LIMIT=8)



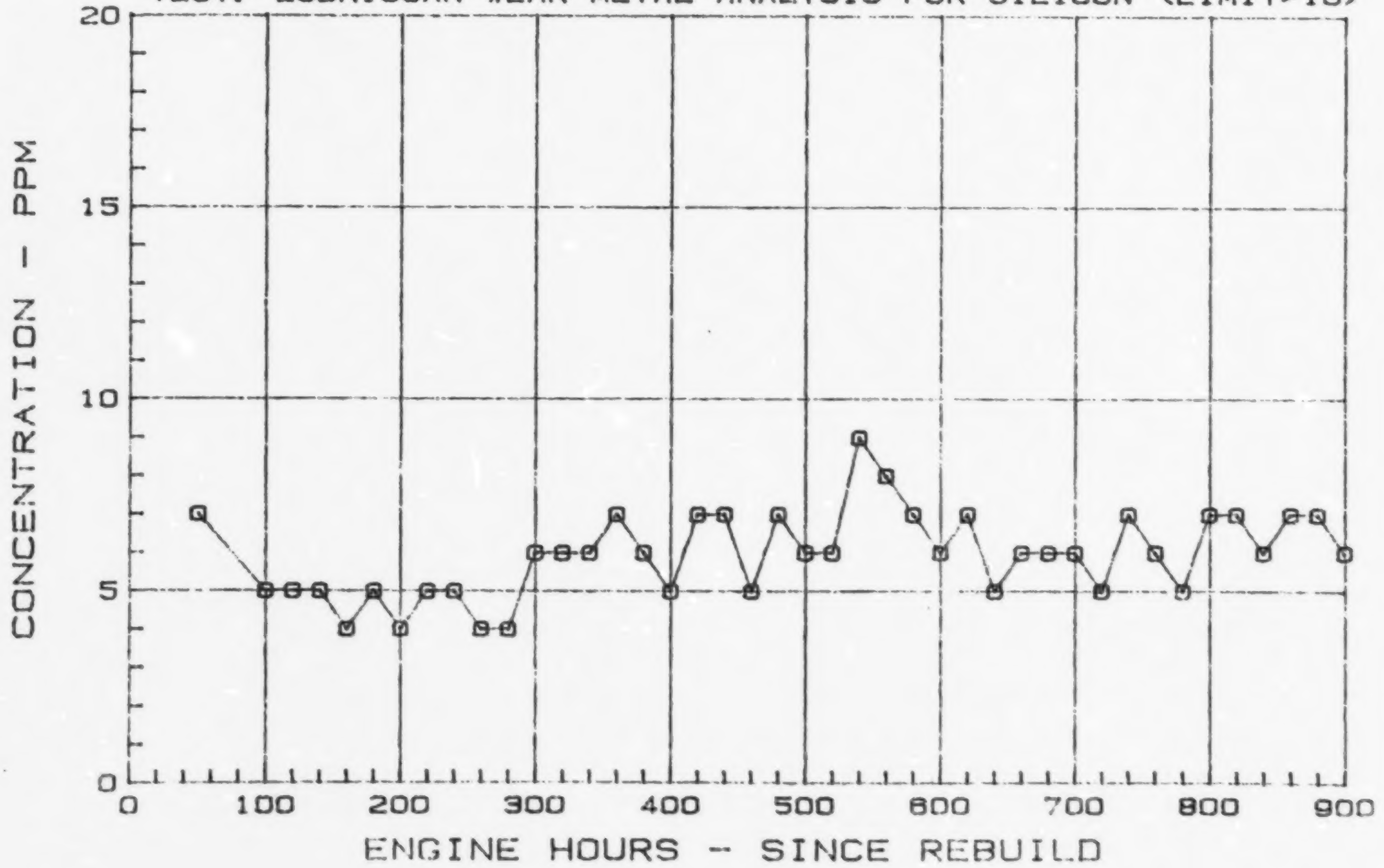
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR SILICON (LIMIT>10)



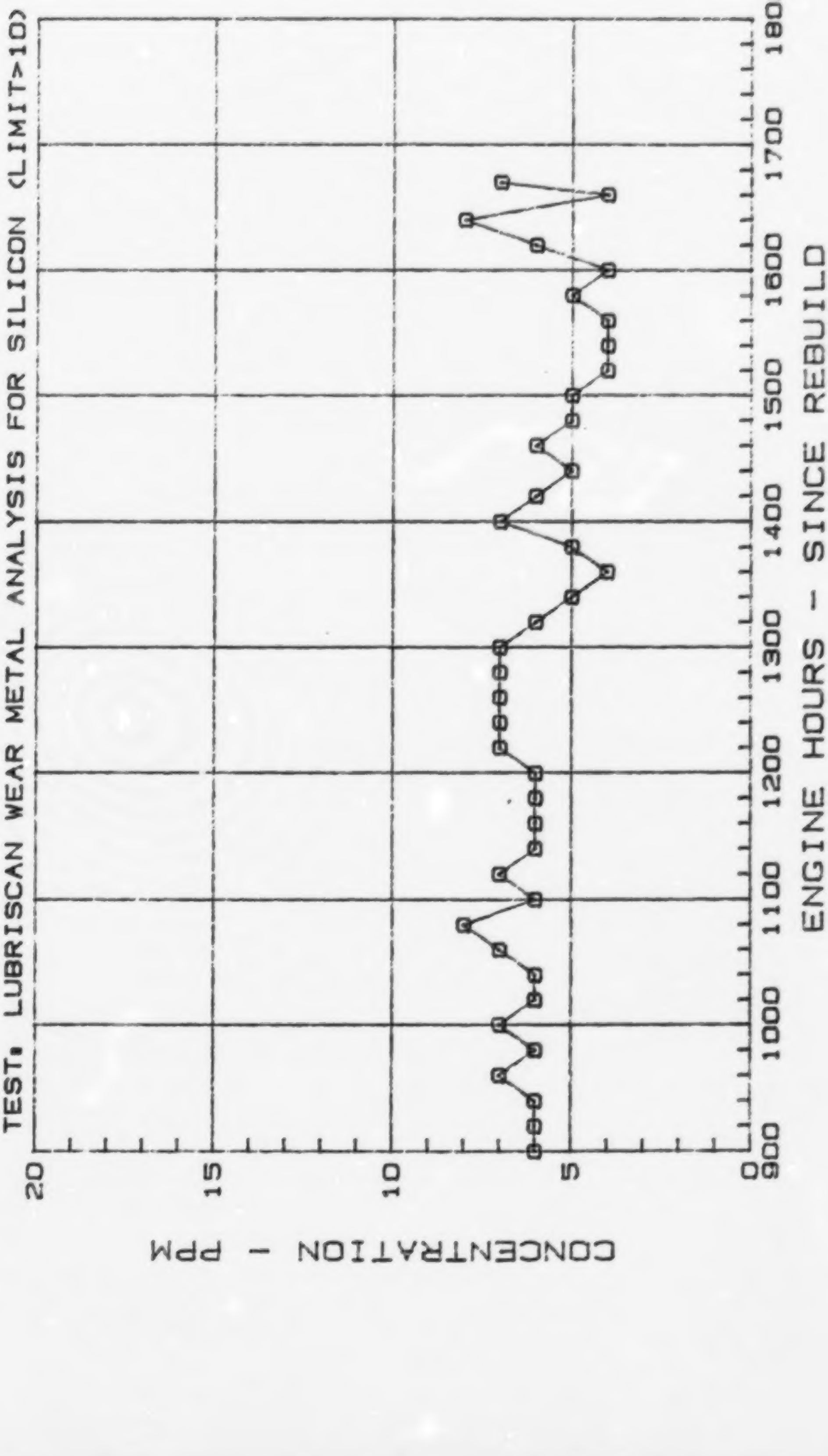
UNIVERSITY OF SASKATCHEWAN–FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. DECEMBER, 1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. LUBRISCAN WEAR METAL ANALYSIS FOR SILICON (LIMIT>10)



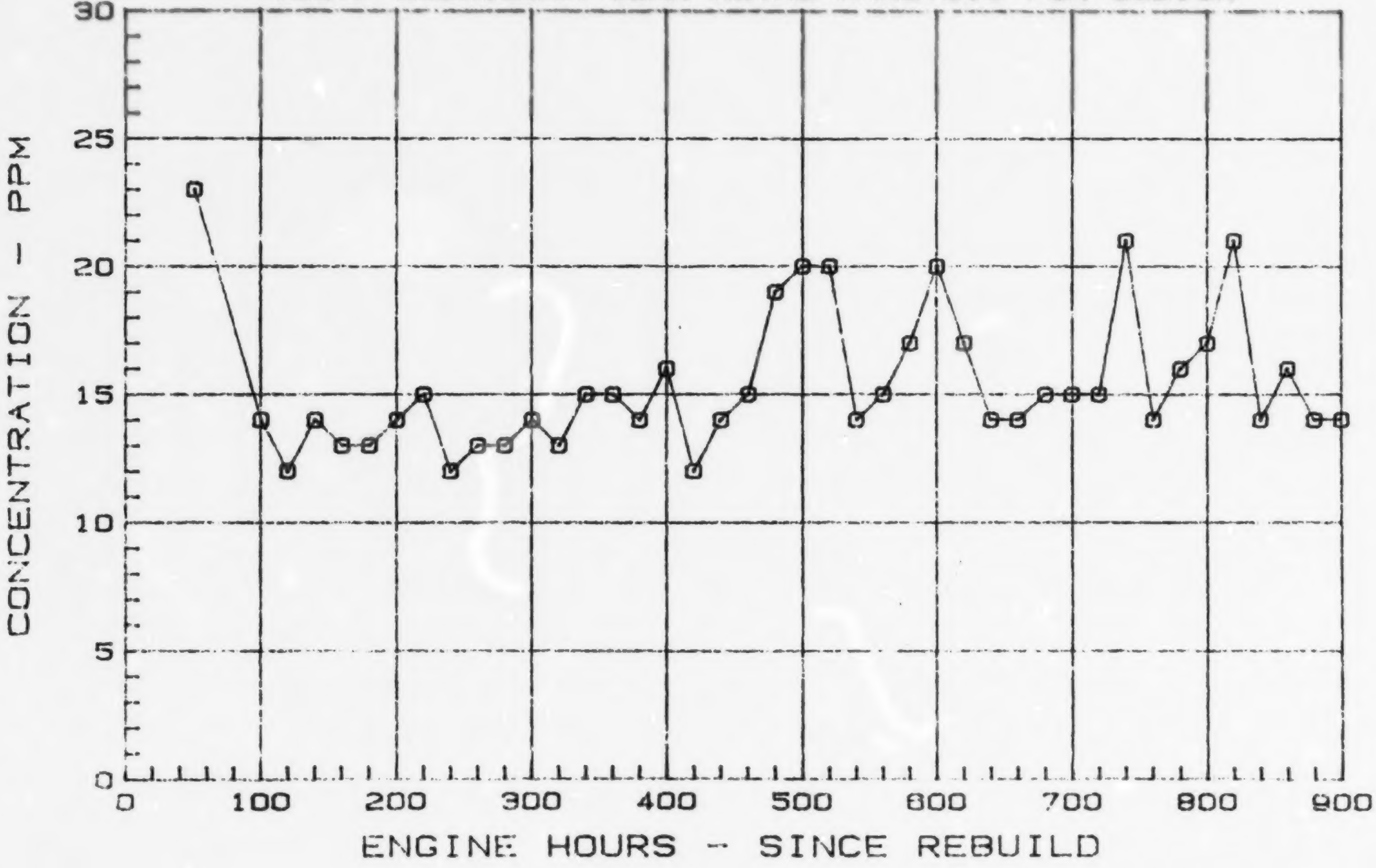
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

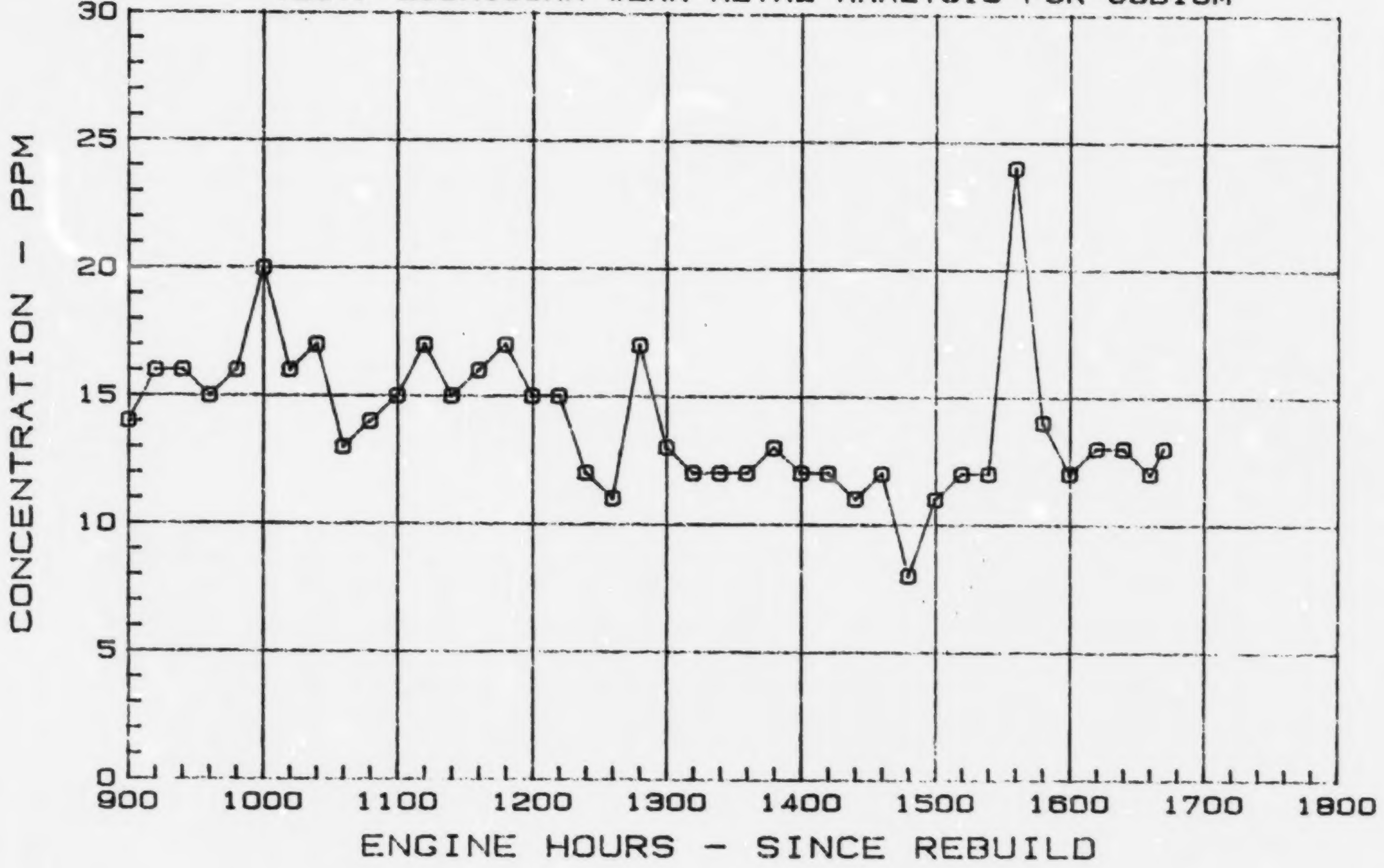
PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR SODIUM





UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ·F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR SODIUM

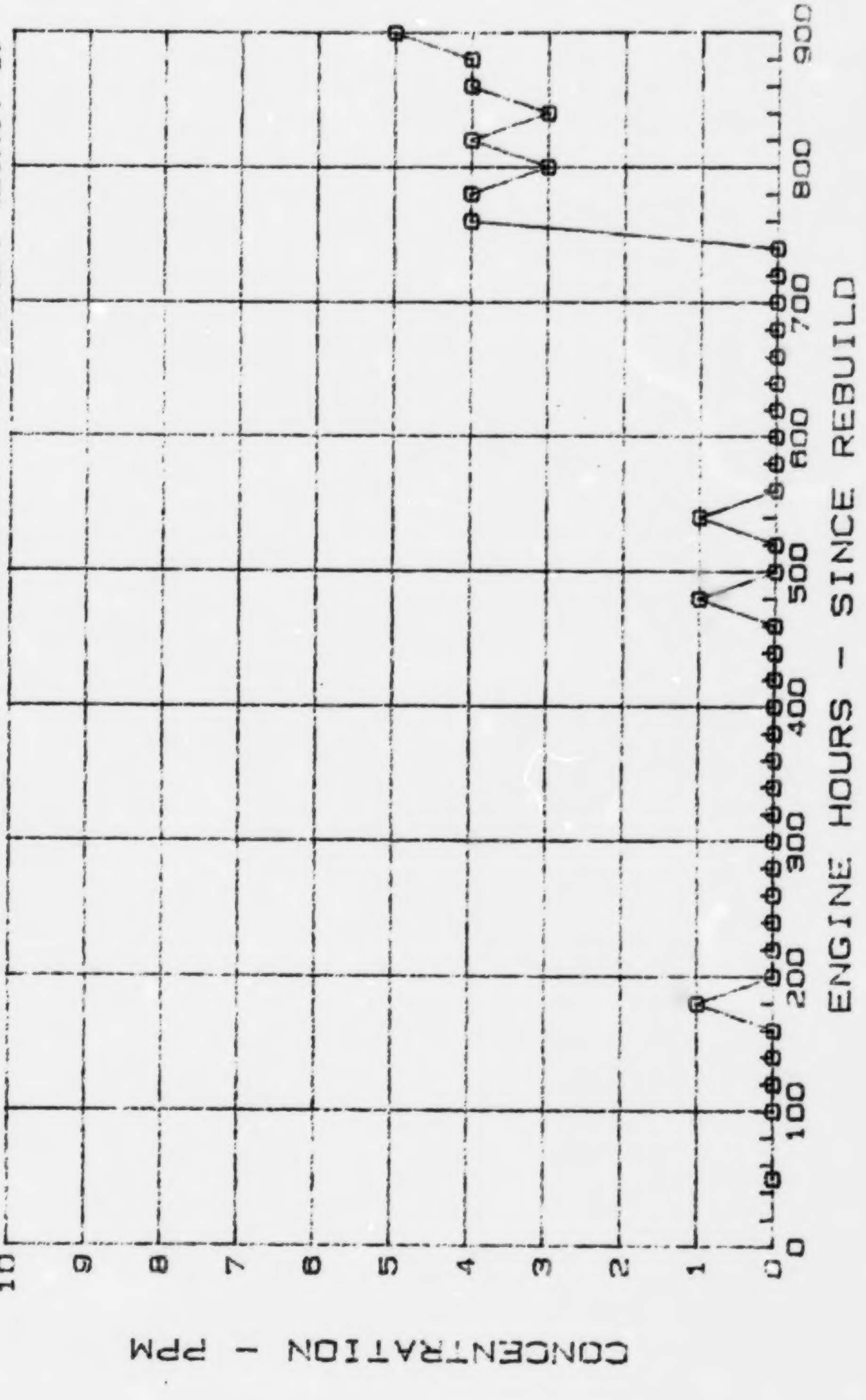
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. DECEMBER.1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. LUBRISCAN WEAR METAL ANALYSIS FOR BORON (LIMIT=3)



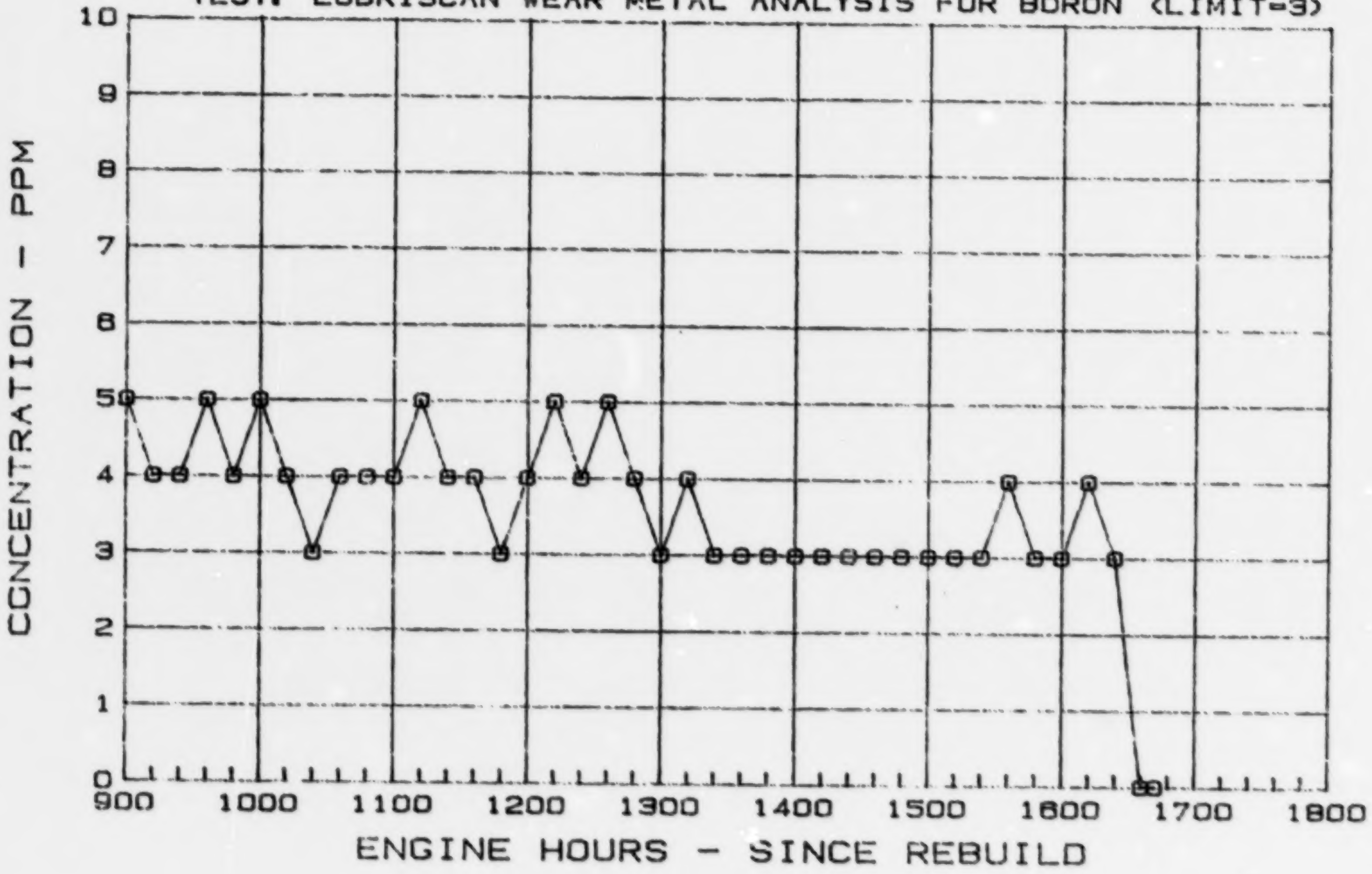
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

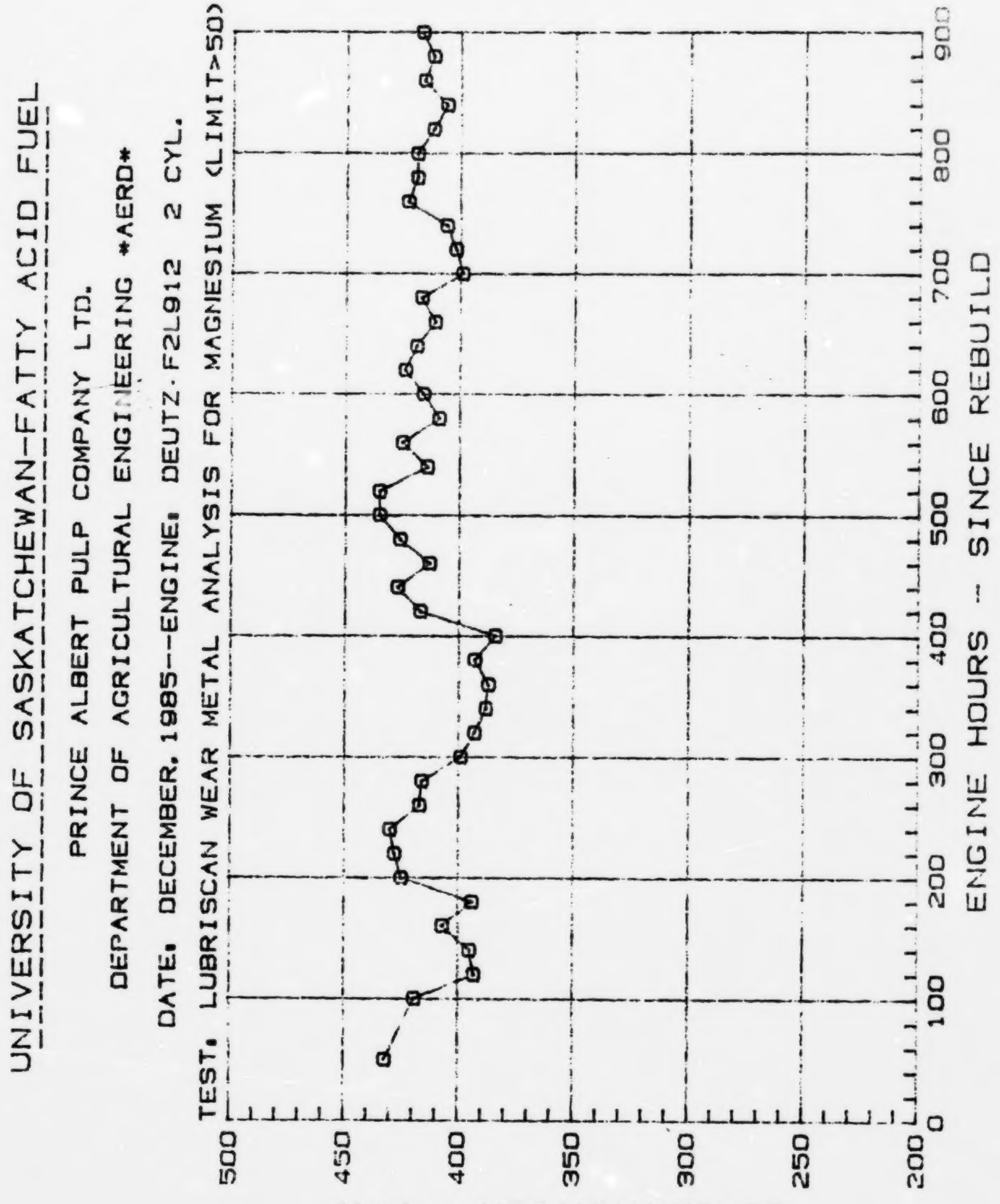
PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR BORON (LIMIT=3)




UNIVERSITY OF SASKATCHEWAN—FATTY ACID FUEL
PRINCE ALBERT PULP COMPANY LTD.
DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*
DATE. DECEMBER, 1985--ENGINE, DEUTZ F2L912 2 CYL.
TEST. LUBRISCAN WEAR METAL ANALYSIS FOR MAGNESIUM (LIMIT>50)
CONCENTRATION - PPM
500
450
400
350
300
250
200
0
100
200
300
400
500
600
700
800
900
ENGINE HOURS - SINCE REBUILD

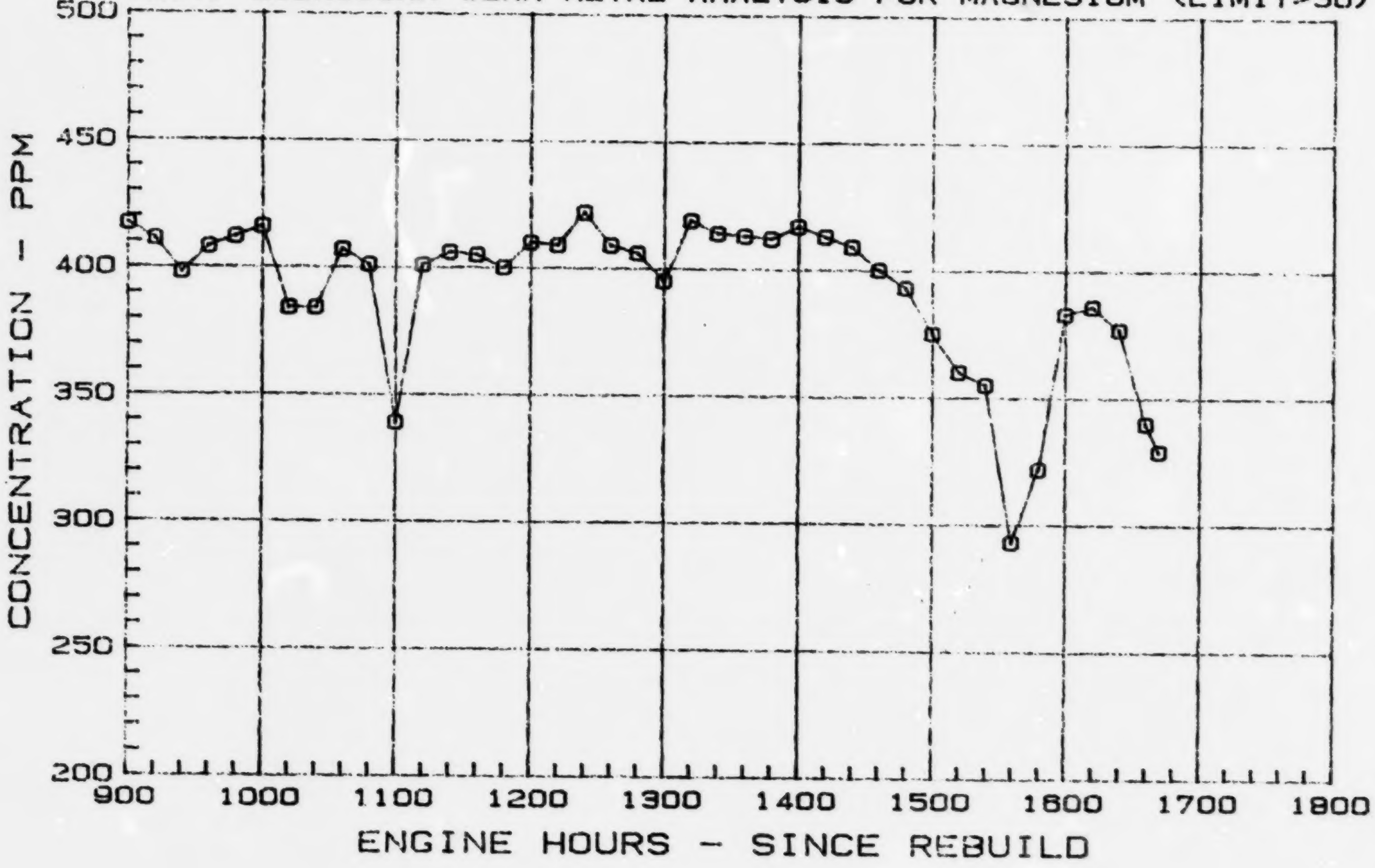
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ·F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR MAGNESIUM (LIMIT>50)



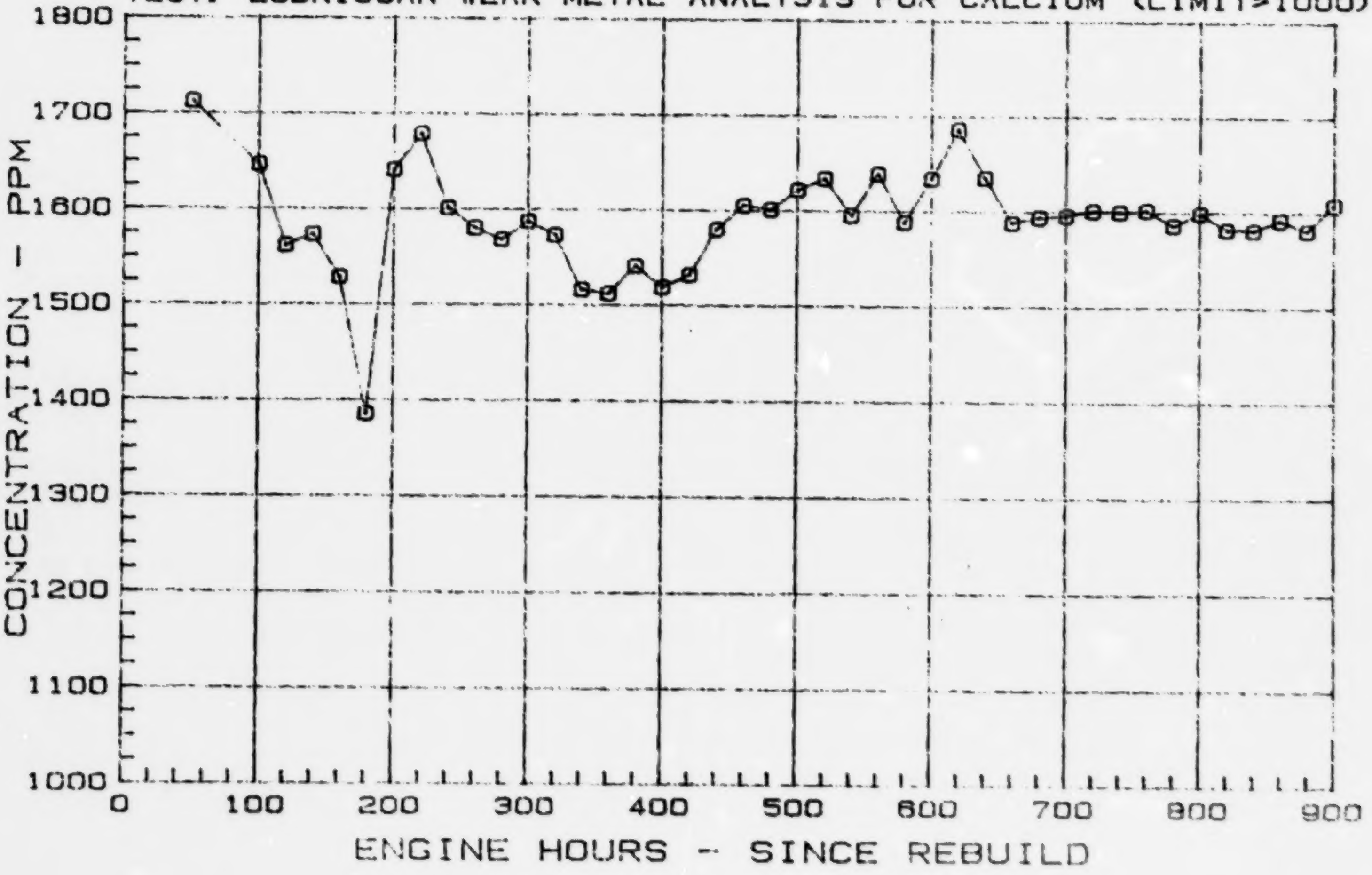
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE. DECEMBER. 1985--ENGINE. DEUTZ F2L912 2 CYL.

TEST. LUBRISCAN WEAR METAL ANALYSIS FOR CALCIUM (LIMIT>1000)



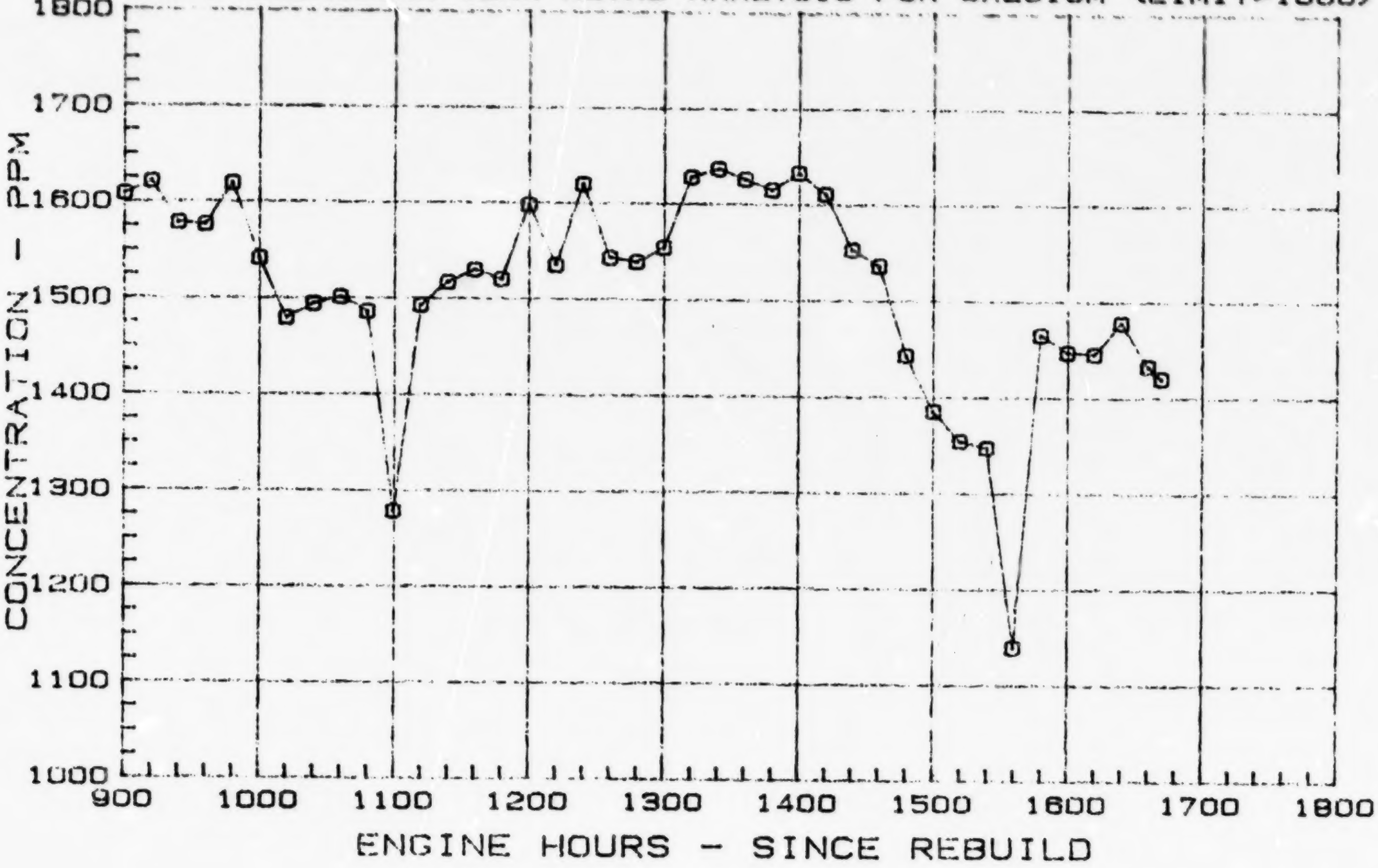
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

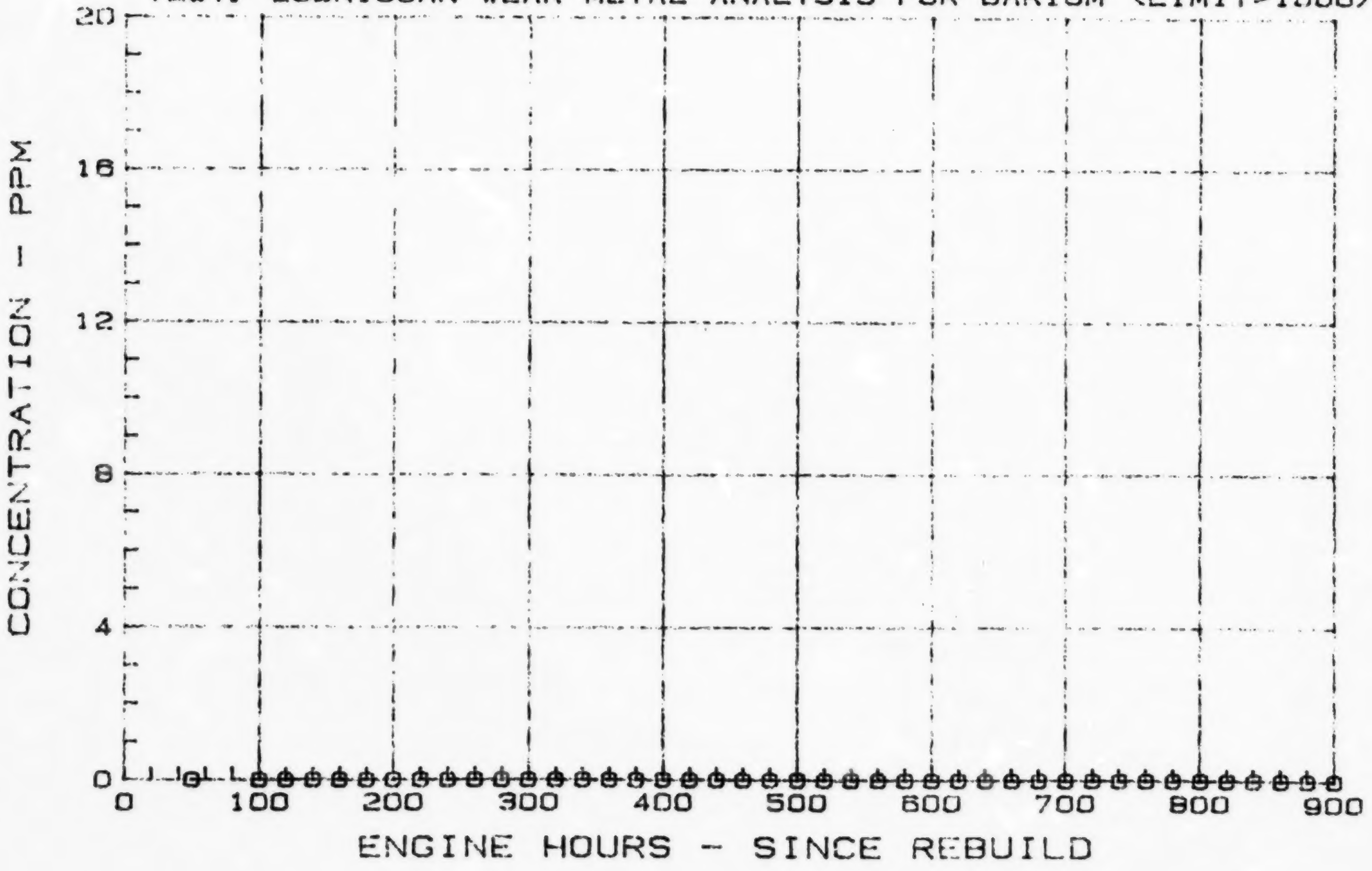
PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR CALCIUM (LIMIT>1000)





UNIVERSITY OF SASKATCHEWAN--FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER. 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR BARIUM (LIMIT>1000)

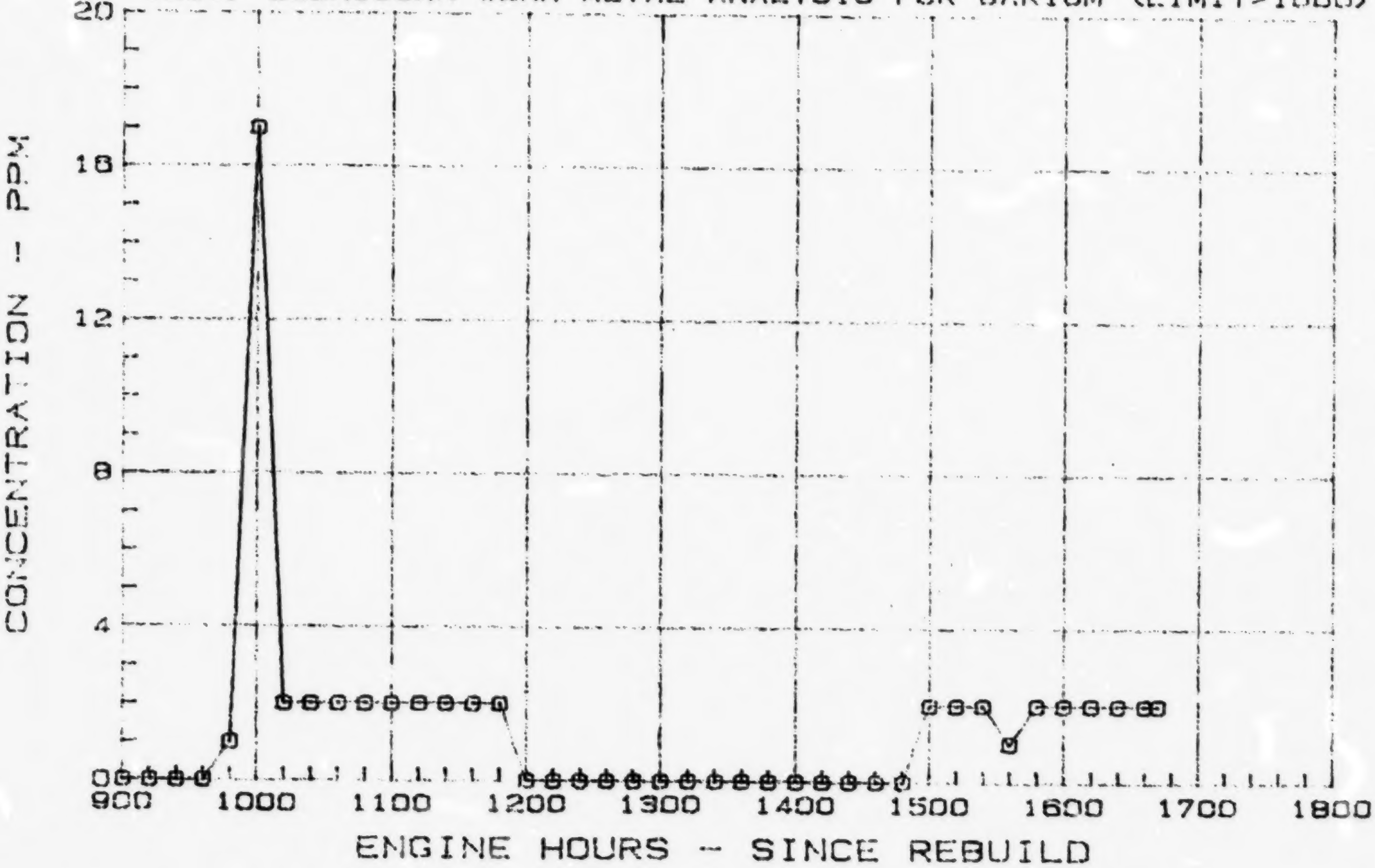
UNIVERSITY OF SASKATCHEWAN--FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985---ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR BARIUM (LIMIT>1000)



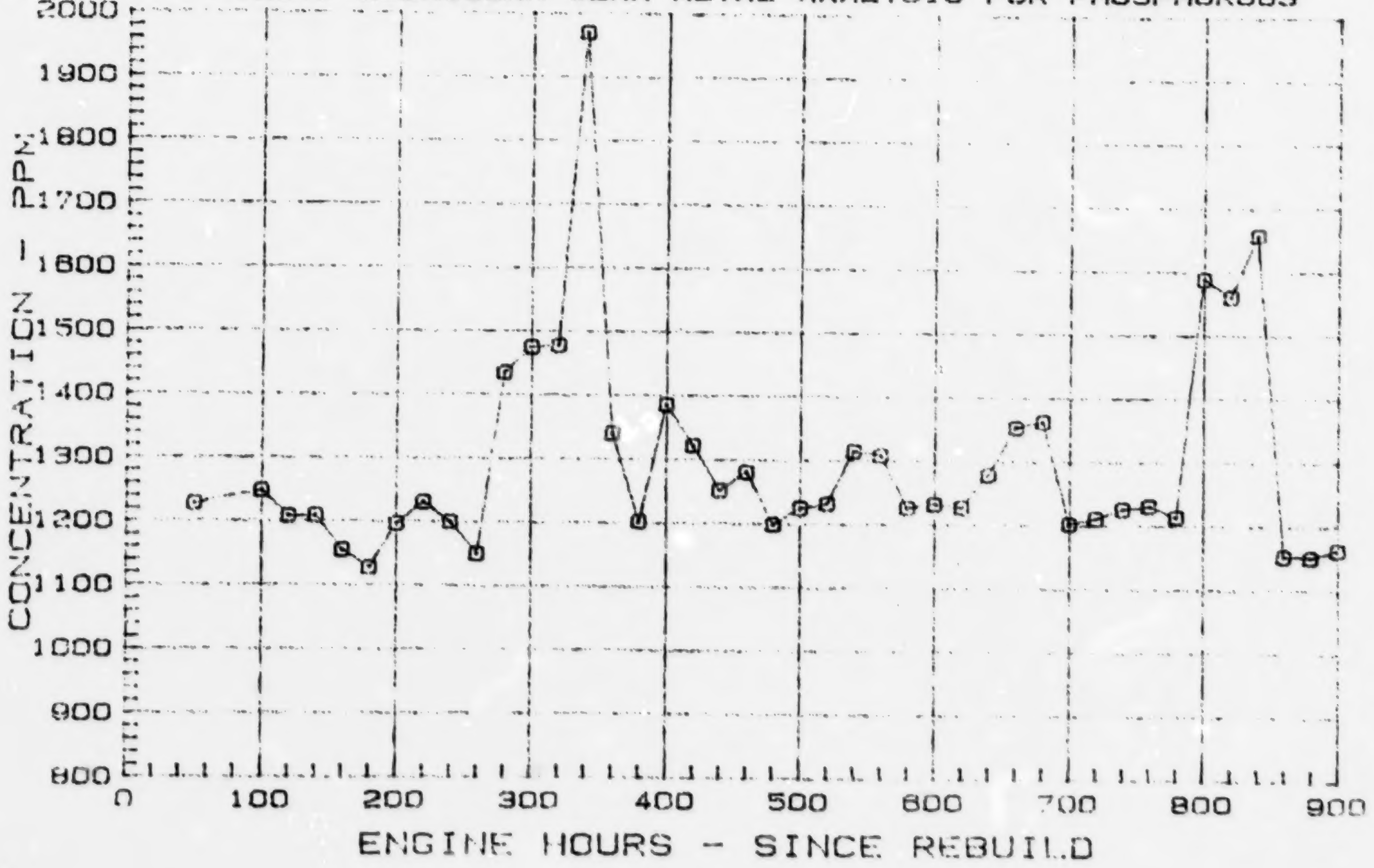
UNIVERSITY OF SASKATCHEWAN--FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985---ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR PHOSPHOROUS



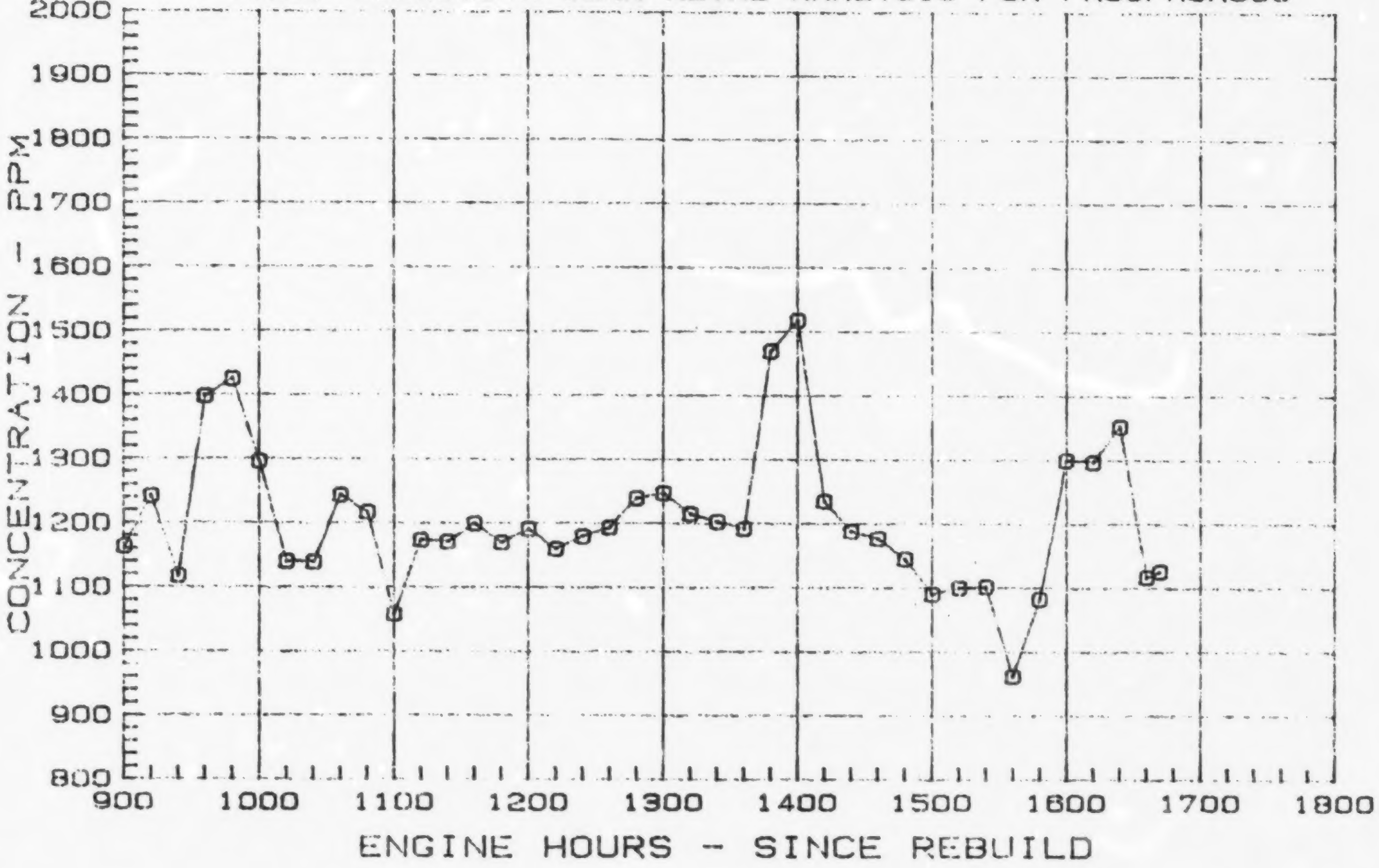
UNIVERSITY OF SASKATCHEWAN–FATTY ACID FUEL

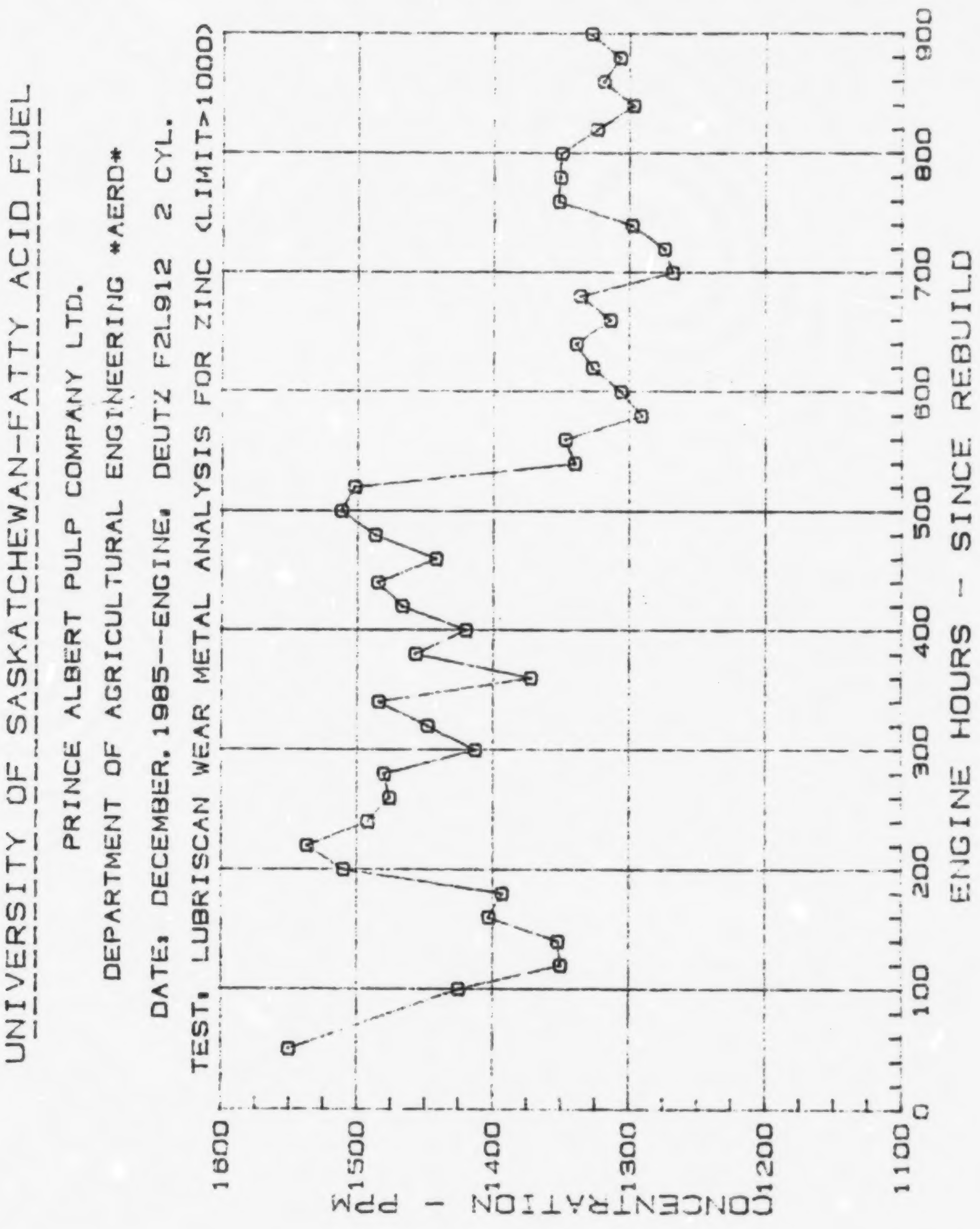
PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985––ENGINE: DEUTZ. F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR PHOSPHOROUS





UNIVERSITY OF SASKATCHEWAN—FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

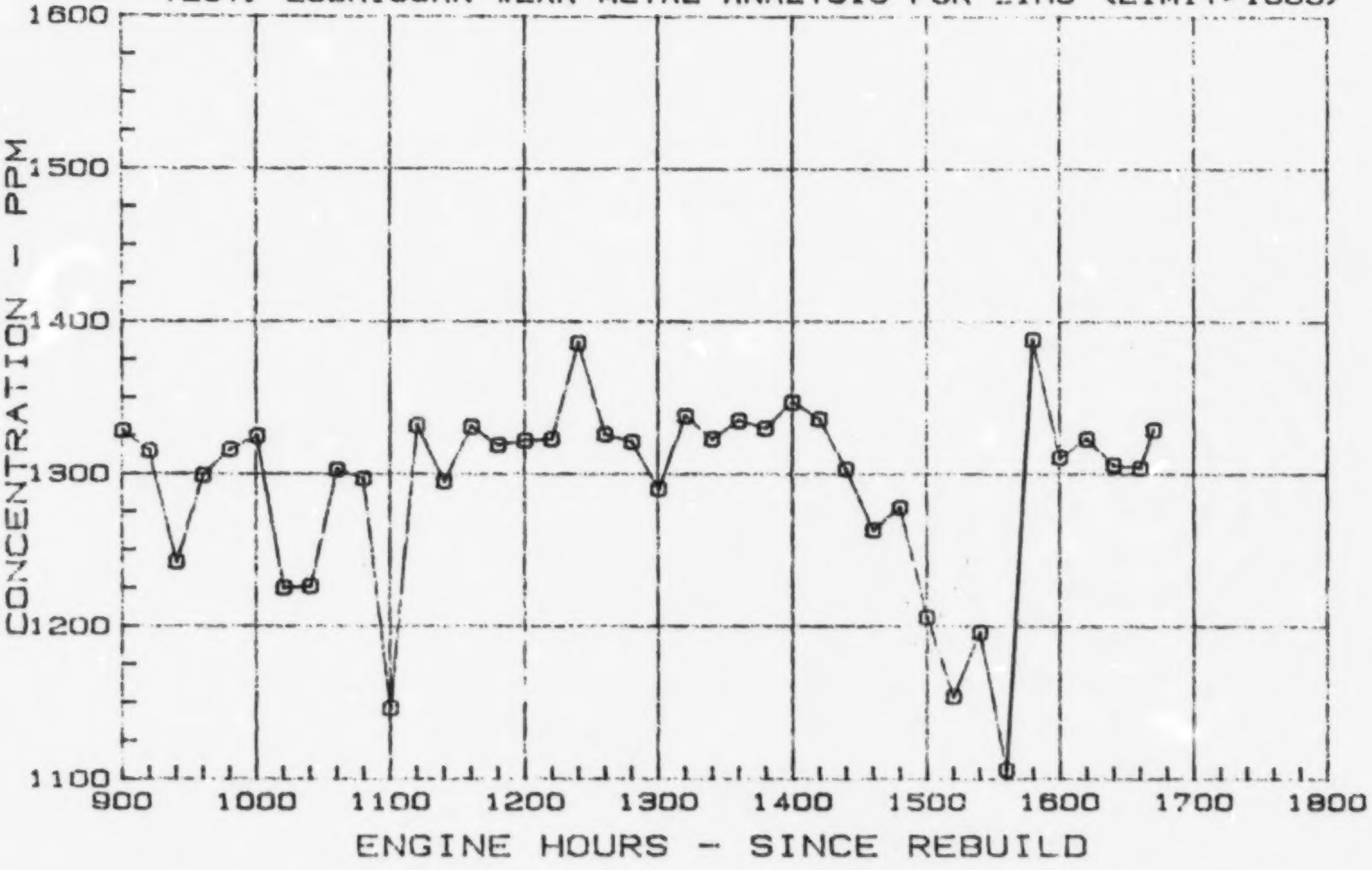
DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE, DECEMBER, 1985--ENGINE, DEUTZ F2L912 2 CYL.

TEST, LUBRISCAN WEAR METAL ANALYSIS FOR ZINC (LIMIT>1000)

UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.
DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*
DATE. DECEMBER, 1985--ENGINE. DEUTZ F2L912 2 CYL.
TEST. LUBRISCAN WEAR METAL ANALYSIS FOR ZINC (LIMIT>1000)



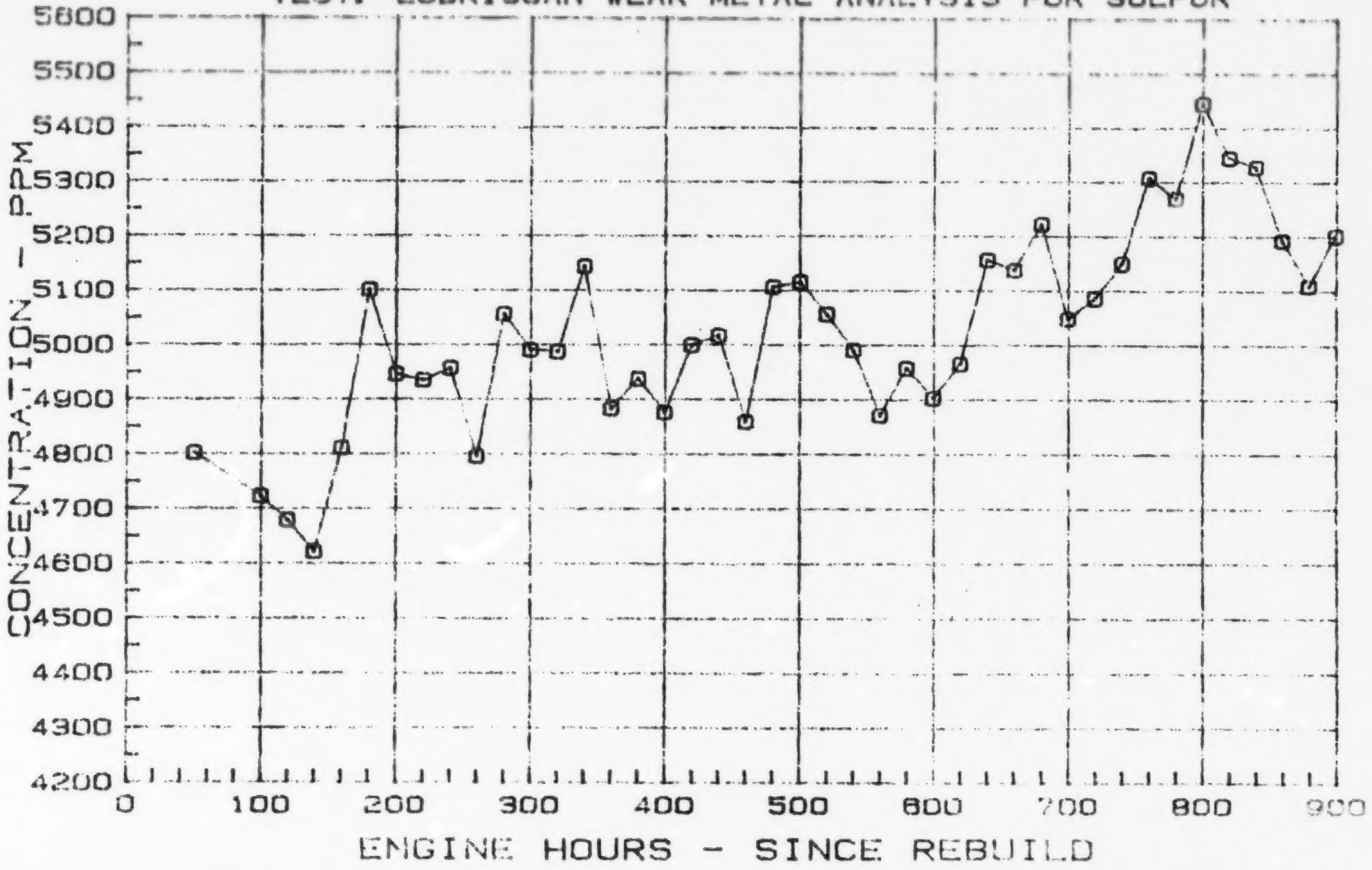
UNIVERSITY OF SASKATCHEWAN-FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR SULFUR



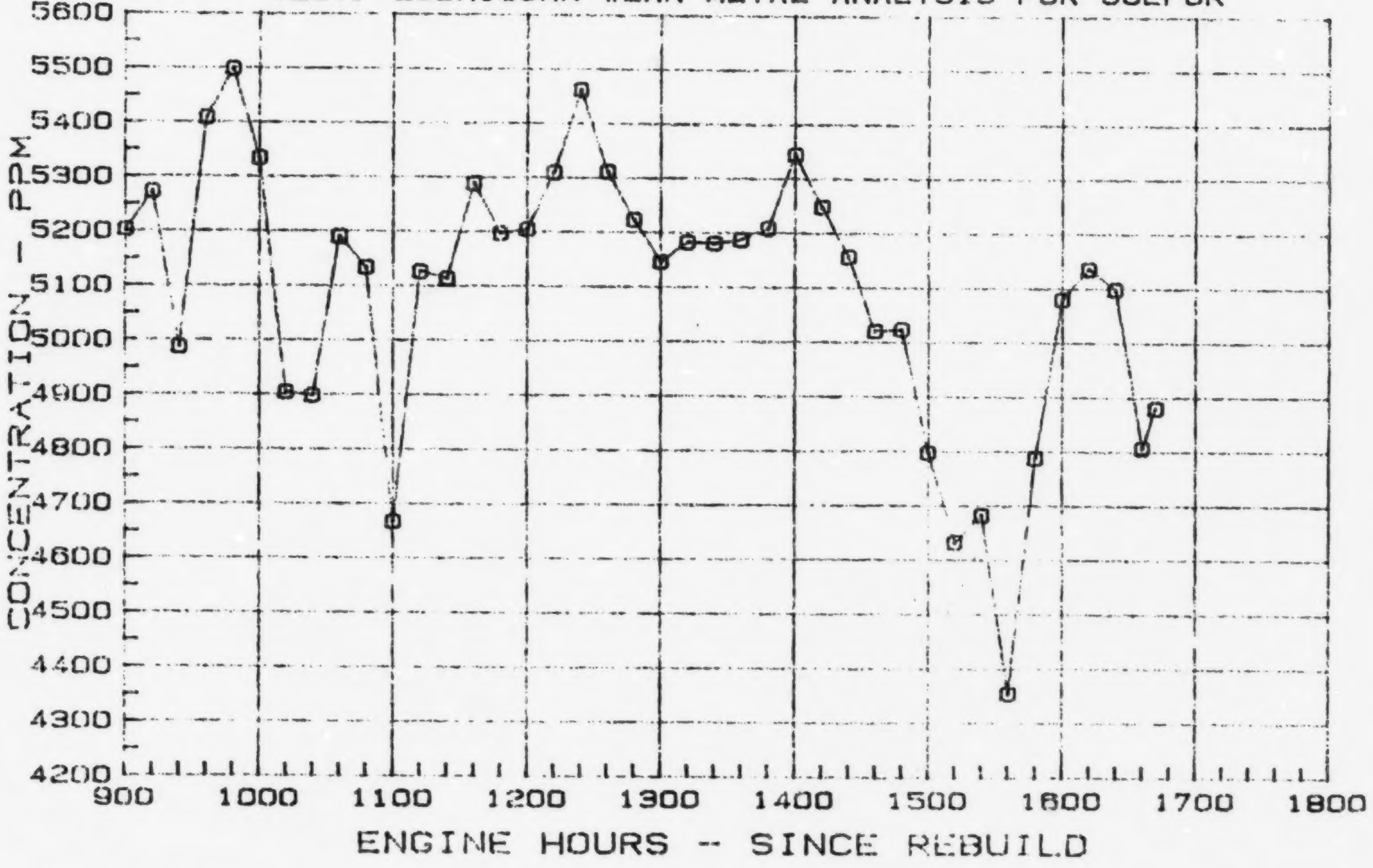
UNIVERSITY OF SASKATCHEWAN–FATTY ACID FUEL

PRINCE ALBERT PULP COMPANY LTD.

DEPARTMENT OF AGRICULTURAL ENGINEERING *AERD*

DATE: DECEMBER, 1985--ENGINE: DEUTZ·F2L912 2 CYL.

TEST: LUBRISCAN WEAR METAL ANALYSIS FOR SULFUR



APPENDIX D

SUMMARY OF ENGINE WEAR MEASUREMENTS
AFTER 1670 HOURS OF OPERATION

Appendix D

Deutz - F2L912 - December, 1985

Summary of Engine Wear Measurements - 1670 Engine Hours
All listed parts replaced at 0 hours.
- Measurements in mm

1. Piston rings

	End Gap	Max Allowable	Side Clearance	Max All
Cylinder #1				
Top ring	0.46	4.0	0.15	0.5
Middle ring	0.66	4.0	0.04	0.5
Oil ring	0.65	2.5	0.04	0.15
Cylinder #2				
Top ring	0.49	4.0	0.15	0.5
Middle ring	0.62	4.0	0.04	0.5
Oil ring	0.55	2.5	0.04	0.15

2. Cylinder liners - Nominal Diameter 100.000 + .020

	Diameter	Out of Round	Taper	Wear	Wear Limit
#1	100.020	.020	.008	.018	.201
#2	100.007	.010	.020	.005	.201

3. a)Valve Guides and Stems

	Stem Diam.	Limit	Guide Bore	Limit	Clearance
#1 Intake	7.945	7.945	8.029-8.049	8.016	.104
Exhaust	7.935	7.920	8.016-8.052	8.016	.117
#2					
Intake	7.943	7.945	8.014-8.032	8.016	.089
Exhaust	7.932	7.920	8.019-8.032	8.016	.100

Nominal Stem Diameter - Intake - 7.960-.015
Exhaust - 7.940-.015
8.000+.015
Guide Bores
Allowable Clearances
Intake - 0.041-.071
Exhaust - .061-.015

b) Valve Springs
Nominal Length - 60.000+1.900
Limit - 56.000
All Springs 58.4

4. Crankshaft Nominal Journal Diameter 62.000-(.010- .028)
Front Journal - 61.974 (main)
Rear Journal - 61.974 (main)

Nominal Bearing Bore (I.D.) - 62.050 + .041
Front Bearing Bore - 62.045
Rear Bearing Bore - 62.070

Nominal Crank Pin Journal Diameter 59.959 + .041
#1 Cylinder - 59.944
#2 Cylinder - 59.949

Nominal Journal to Bearing Clearance .041 - .099
#1 Cylinder .094
#2 Cylinder .099

No measureable out of round on any crankshaft journals.
Centre Journal Nominal Diameter 70.000-.028
Measured 69.982

5. Camshaft
No measurable out of round on any of the journals.
Nominal lift - 8.000
Limit value = N/A

Cam# (rear to front)	Lift
1	7.920
2	7.915
3	7.922
4	7.930

	Bearing bore	Journal diameter	Clearance
Front	52.057	51.943	.114
Middle	52.004	51.925	.079
Rear	47.993	47.955	.038

6. Wrist Pins
Nominal Diameter of Pins - 35.000 - .005
Nominal bore of Bearings - 35.039 + .046

Nominal Clearance - .041 - .091
Clearance Limit - .249

	Pin diam.	Bearing Bore	Clearance
#1	34.999	35.077	.078
#2	34.999	35.065	.066

APPENDIX E

REPORT FROM

HANSON MATERIALS ENGINEERING

ON

SELECTED ENGINE COMPONENTS

hanson materials engineering
consulting engineers
7450 - 18 street, edmonton, alberta, canada T6P 1N8
Tel. (403) 464-7916 (24 hours) Telex 037-3755 Telefax (403) 464-4175

January 17, 1985.

University of Saskatchewan,
Dept of Agricultural Engineering,
Saskatoon, Saskatchewan. S7N 0W0

Attention: Mr. Bill Reid.

Subject: Evaluation of Diesel Engine Components.

1.0 Introduction:

The diesel engine fuel system components and bearing shell shown in Figure 1 were received for investigation on December 23, 1985.

It was requested that the pieces be examined for evidence of corrosion, wear and fouling as part of a program evaluating different fuels. The results are compared where possible to those obtained in a similar analysis reported to you on August 19, 1985 (our report E85-7-1078).

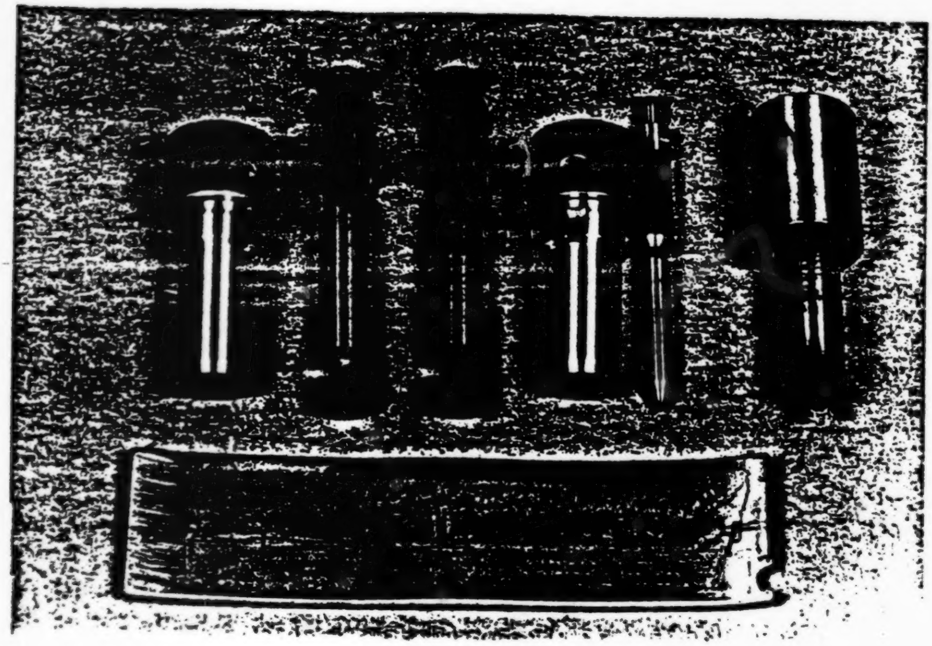


FIGURE 1.

COMPONENTS OF DIESEL ENGINE
AS RECEIVED FOR EVALUATION.

2.0 **Investigation:**

2.1 Bearing Shell.

The bearing shell was examined under the stereomicroscope at magnification up to 50X. As shown in Figure 2, significant corrosion pitting had occurred over much of the bearing surface. The presence of initial machining marks on the bearing indicates that the bearing had not operated under excessive loads or for extended periods.

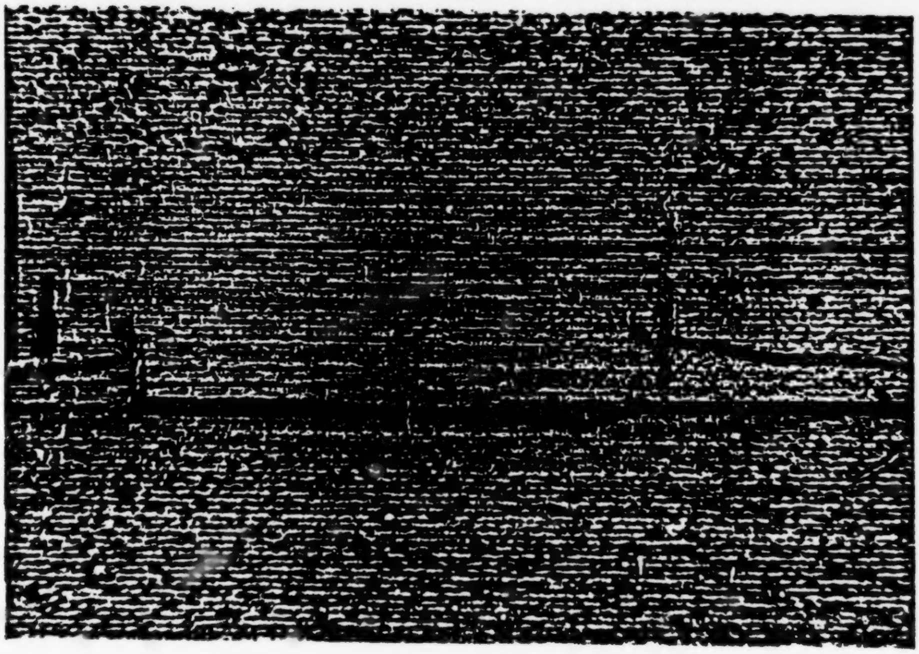


FIGURE 2.

CLOSE UP OF BEARING SHELL SURFACE. NOTE PRESENCE OF INITIAL MACHINING MARKS AND CORROSION PITS.

2.2 Injector Plungsrs and Barrels:

Two plungers and barrels were examined for damage. Figure 3 shows the most apparent wear area on one plunger. Examination of this region under the metallurgical microscope found that the mark was a result of slight wear. There was no evidence of corrosion seen comparable to that observed on the previously examined parts; there were no areas of corrosion found anywhere on the plunger.

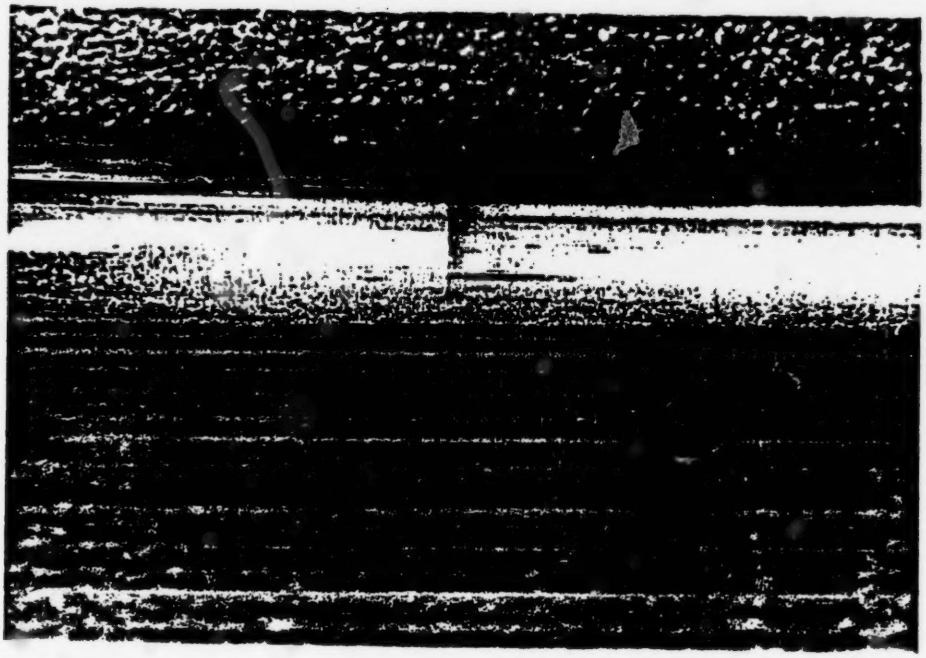


FIGURE 3.

CLOSE UP OF INJECTOR PLUNGER SHOWING CIRCUMFERENTIAL WEAR BAND. NO CORROSION WAS ASSOCIATED WITH THIS BAND.

2.3 Injector Tip:

The needle area of the injector tip, shown in Figure 4 was seen to have a deposit adhering to the point and some corrosion on the conical section. The straight sections of the shaft exhibited slight wear but no corrosion.

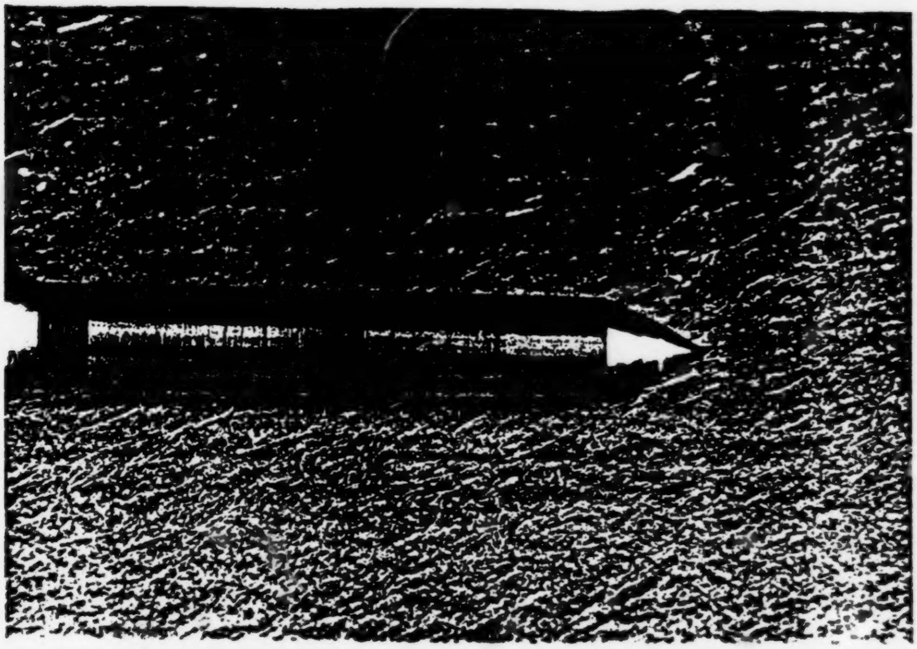


FIGURE 4.

INJECTOR TIP SHOWING DEPOSIT ON END.

Under the scanning electron microscope, some of the deposit was evident on the tip; Figure 5. The adjacent corroded area may also be seen in this photo. The corrosion is shown at higher magnification in Figure 6.

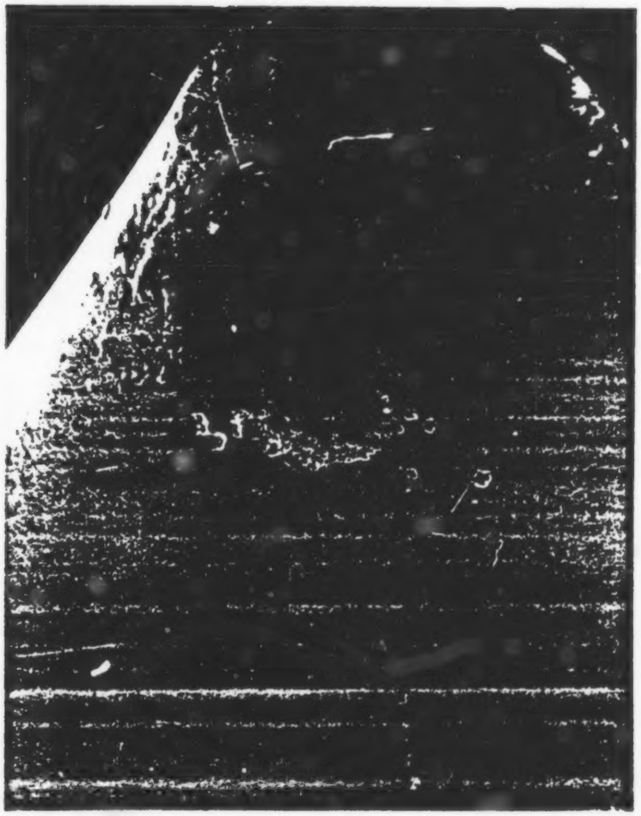


FIGURE 5. MAG. X 54.

SCANNING ELECTRON MICROGRAPH OF INJECTOR TIP SHOWING DEPOSIT AND CORRODED AREAS.

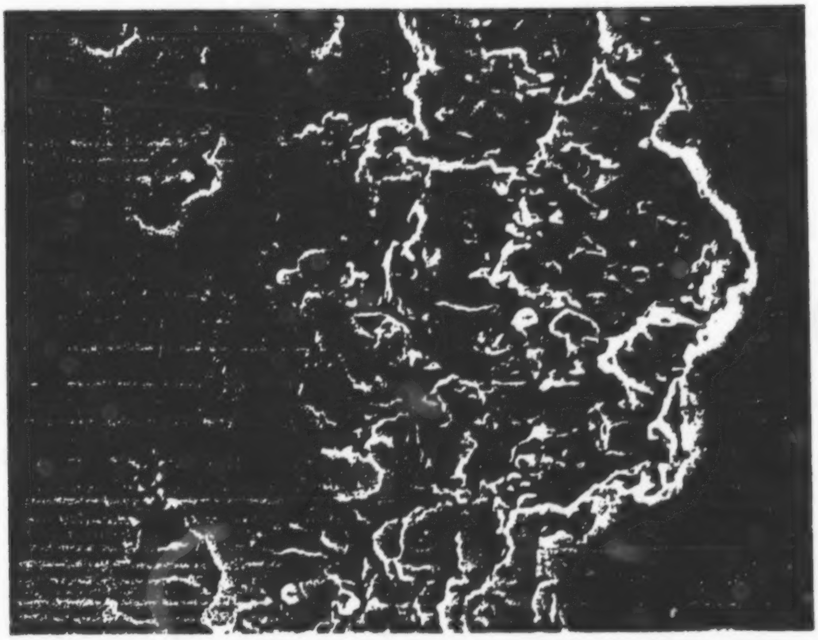


FIGURE 6. MAG. X 2350.

HIGH MAGNIFICATION VIEW OF CORRODED AREA.

3.0 Comments:

When comparing the injector plungers to those previously examined, it is apparent that less corrosion and wear is present on the present samples. The presence of corroded areas on the bearing shell and injector tip shows that there are still some corrosive elements in the fuel system.

The deposit on the point of the injector tip was not analyzed but its black colour and behaviour during cleaning were similar to normal carbon deposits.

4.0 Conclusions:

4.1 The injector plungers examined were found to have very little wear and no corrosion. As such, they were in better condition than similar plungers examined previously.

4.2 Corrosion was evident on both the bearing shell and injector tips.

Yours very truly,
HANSON MATERIALS ENGINEERING

E.C. (Ted) Hamre, Ph.D., P.Eng.

ECH/et
E85-12-1748

PROFESSIONAL ENGINEER ALBERTA
DR. E.C. HAMRE

PERMIT TO PRACTICE
Hanson Materials Engineering (Alberta) Limited
Practicing Under Hanson Materials Engineering
Signature
Date 1986 01 17
PERMIT NUMBER: P 4144
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

PROFESSIONAL ENGINEER SASKATCHEWAN
E. C. HAMRE
EDMONTON